FERGUSON'S ASTRONOMY.

ASTRONOMY,

EXPLAINED UPON

SIR ISAAC NEWTON'S PRINCIPLES.

BY

JAMES FERGUSON, F.R.S.

WITH

NOTES, AND SUPPLEMENTARY CHAPTERS.

BY

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PREFACE

OF

THE EDITOR.

In presenting to the Public a new and enlarged edition of Ferguson's Astronomy, the Editor has been particularly solicitous to collect all the discoveries in the science which have been made during the last thirty years, and to present them in a simple and unassuming form suited to the popular nature of the original work. These discoveries, which are contained in Twelve supplementary Chapters, relate chiefly to the physical constitution of the Old and New Planets of the Solar System, and to the various and wonderful phenomena which are displayed in the region of the Fixed Stars.

In accomplishing this task, the Editor can claim no other merit but that of having brought together a

number of curious facts, which had not hitherto been collected, and many of which have never appeared in any English work. In this new edition, various additions and improvements have been made, and an additional Chapter has been added on Practical Astronomy.

Edinburgh, February 1, 1821.

ASTRONOMY

EXPLAINED UPON

SIR ISAAC NEWTON'S PRINCIPLES.

CHAP. XXII.

A DESCRIPTION OF THE ASTRONOMICAL MACHINERY, SERVING TO EXPLAIN AND ILLUSTRATE THE FOREGOING PART OF THIS TREATISE.

379. THE ORRERY. This machine shews the motions of the Sun, Mercury, Venus, Earth, and Moon; and occasionally the superior planets, Mars, Jupiter, and Saturn, may be put on; Jupiter's four satellites are moved round him in their proper times by a small winch; and Saturn has his five satellites, and the ring which keeps his parallelism round the Sun; and by a lamp put in the Sun's place, the ring shews all the phases described in the 204th article. Plate I. Frontispiece. The Orrery.

In the centre, No. 1, represents the Sun, supported by its axis inclining almost 8 degrees from the axis of the ecliptic; and turning round in 25¼ days on its axis, of which the north pole inclines towards the 8th degree of Pisces in the great ecliptic (No. 11), whereon the months and days are engraven over the signs and degrees in which the Sun appears, as seen from the Earth, on the different days of the year. The Sun. The ecliptic.

The nearest planet (No. 2) to the sun is Mercury, which goes round him in 87 days 23 hours, or 87⅔ diurnal rotations of the Earth; but has no motion round its axis in the machine, because the time of its diurnal motion in the heavens is not known to us. Mercury.

Venus. The next planet in order is Venus (No. 3), which performs her annual course in 224 days 17 hours and turns round her axis in 24 days 8 hours, or in 24⅓ diurnal rotations of the Earth. Her axis inclines 75 degrees from the axis of the ecliptic, and her north pole inclines towards the 20th degree of Aquarius, according to the observations of Bianchini. She shews all the phenomena described from the 30th to the 44th article of Chap. I.

The Earth. Next without the orbit of Venus is the Earth (No. 4), which turns round its axis, to any fixed point at a great distance, in 23 hours 56 minutes 4 seconds of mean solar time (§ 221, *et seq.*), but from the Sun to the Sun again in 24 hours of the same time. No. 6 is a sydereal dial-plate under the Earth; and No. 7 a solar dial-plate on the cover of the machine. The index of the former shews sydereal, and of the latter solar time; and hence the former index gains one entire revolution on the latter every year, as 365 solar or natural days contain 366 sydereal days, or apparent revolutions of the stars. In the time that the Earth makes 365¼ diurnal rotations on its axis, it goes once round the Sun in the plane of the ecliptic, and always keeps opposite to a moving index (No. 10), which shews the Sun's apparent daily change of place, and also the days of the months.

The orrery demonstrates the change of seasons, The Earth is half covered with a black cap, for dividing the apparently enlightened half next the Sun from the other half, which, when turned away from him, is in the dark. The edge of the cap represents the circle bounding light and darkness, and shews at what time the Sun rises and sets to all places throughout the year. The Earth's axis inclines 23½ degrees from the axis of the ecliptic, the north pole inclines towards the beginning of Cancer, and keeps its parallelism throughout its annual course (§ 48, 202); so that in summer the northern parts of the Earth incline towards the Sun, and in winter from him: by which means the different lengths of days and nights, and the cause of the various seasons, are demonstrated to sight.

and shews the beginning of twilight, time of sun-rising, &c. There is a broad horizon, to the upper side of which is fixed a meridian semicircle in the north and south points, graduated on both sides from the horizon to 90° in the zenith, or vertical point. The edge of the horizon is graduated from the east and west to the

south and north points, and within these divisions are the points of the compass. From the lower side of this thin horizon-plate stand out four small wires, to which is fixed a twilight circle 18 degrees from the graduated side of the horizon all round. This horizon may be put upon the Earth (when the cap is taken away), and rectified to the latitude of any place: and then, by a small wire called *the solar ray*, which may be put on so as to proceed directly from the Sun's centre towards the Earth's, but to come no farther than almost to touch the horizon, the beginning of twilight, time of sun-rising, with his amplitude, meridian altitude, time of setting, amplitude then, and end of twilight, are shewn for every day of the year at that place to which the horizon is rectified.

The Moon.

The Moon (No. 5) goes round the Earth, from between it and any fixed point at a great distance, in 27 days 7 hours 43 minutes, or through all the signs and degrees of her orbit, which is called *her periodical revolution*; but she goes round from the Sun to the Sun again, or from change to change, in 29 days 12 hours 45 minutes, which is *her synodical revolution*; and in that time she exhibits all the phases already described, § 255.

The Orrery shews the Moon's rising and setting, &c.

When the above-mentioned horizon is rectified to the latitude of any given place, the times of the Moon's rising and setting, together with her amplitude, are shewn to that place, as well as the Sun's; and all the various phenomena of the harvest Moon (§ 273, *et seq.*), are made obvious to sight.

and her latitude and distance from her nodes;

The Moon's orbit (No. 9) is inclined to the ecliptic (No. 11), one-half being above, and the other below it. The nodes, or points at 0 and 0, lie in the plane of the ecliptic, as described § 317, 318, and shift backward through all its signs and degrees in 18⅔ years. The degrees of the Moon's latitude, to the highest at *N L*, north latitude, and lowest at *S L*, south latitude, are engraven both ways from her nodes at 0 and 0; and, as the Moon rises and falls in her orbit according to its inclination, her latitude and distance from her nodes are shewn for every day; having first rectified her orbit, so as to set the nodes to their proper places in the ecliptic, and then, as they come about at different, and almost opposite times of the year (§ 319), and point twice towards the Sun, all the eclipses may be shewn

for hundreds of years (without any new rectification), by turning the machinery backward for time past, or forward for time to come. At 17 degrees distance from each node, on both sides, is engraved a small sun, and at 12 degrees distance a small moon, which shews the limits of solar and lunar eclipses (§ 317); and when, at any change, the Moon falls between either of these suns and the node, the Sun will be eclipsed on the day pointed to by the annual index (No. 10), and, as the Moon has then north or south latitude, one may easily judge whether that eclipse will be visible in the northern or southern hemisphere, especially as the Earth's axis inclines towards the Sun, or from him at that time. And when, at any full, the Moon falls between either of the little moons and node, she will be eclipsed, and the annual index shews the day of that eclipse. There is a circle of 29½ equal parts (No 8), on the cover of the machine, on which an index shews the days of the Moon' age.

and consequently the eclipses of the Sun and Moon.

The Orrery shews the tides, Plate IX. Fig. 10;

A semi-ellipsis and semi-circle are fixed to an elliptical ring, which being put like a cap upon the Earth, and the forked part *F* upon the Moon, shews the tides as the Earth turns round within them, and they are led round it by the Moon. When the different places come to the semi-ellipsis *A a E b B*, they have tides of flood; and when they come to the semicircle *C E D*, they have tides of ebb (§ 304, 305); the index on the hour-circle (No. 7) shewing the times of these phenomena.

and also the direct and retrograde motions of Venus and Mercury.

There is a jointed wire, of which one end being put into a hole in the upright stem that holds the Earth's cap, and the wire laid into a small forked piece which may be occasionally put upon Venus or Mercury, shews the direct and retrograde motions of these two planets, with their stationary times and places, as seen from the Earth.

The whole machinery is turned by a winch or handle (No. 12), and is so easily moved, that a clock might turn it without any danger of stopping.

To give a plate of the wheel-work of this machine would answer no purpose, because many of the wheels lie so behind others, as to hide them from sight in any view whatsoever.

398. ANOTHER ORRERY.—In this machine, which is the simplest I ever saw, for shewing the diurnal and annual motions of the Earth, together with the motion of the Moon and her nodes, *A* and *B* are two oblong square plates held together by four upright pillars, of which three appear at *f*, *g*, and *g* 2. Under the plate *A* is an endless screw on the axis of the handle *h*, which works in a wheel fixed on the same axis with the double-grooved wheel *E*: and on the top of this axis is fixed the toothed wheel *i*, which turns round the pinion *k*, on the top of whose axis is the pinion *k* 2, which turns another pinion *b* 2, and this turns a third, on the axis *a* 2, on which is the Earth *U* turning round; this last axis inclining 23½ degrees. The supporter *X* 2, in which the axis of the Earth turns, is fastened to the moveable plate *C*.

Another Orrery, for shewing the motions of the Earth and Moon. Plate VI. Fig. 1.

In the immoveable plate *B*, beyond *H*, is fixed the strong wire *d*, on which hangs the Sun *T*, so that it may turn round the wire. To this Sun is fixed the wire or solar ray *Z*, which (as the Earth *U* turns round its axis), points to all the places that the Sun passes vertically over, every day of the year. The Earth is half-covered with a black cap *a*, as in the former orrery, for dividing the day from the night; and as the different places come out from below the edge of the cap, or go in below it, they shew the times of sun-rising and setting every day of the year. This cap is fixed on the wire *b*, which has a forked piece *C* turning round the wire *d*: and, as the Earth goes round the Sun, it carries the cap, wire, and solar ray round him; so that the solar ray constantly points towards the Earth's centre.

On the axis of the pinion *k* is the pinion *m*, which turns a wheel on the cock or supporter *n*, and on the axis of this wheel nearest *n* is a pinion (hid from view), under the plate *C*, which pinion turns a wheel that carries the Moon *V* round the Earth *U*; the Moon's axis rising and falling in the socket *W*, which is fixed to the triangular piece above *Z*; and this piece is fixed to the top of the axis of the last-mentioned wheel. The socket *W* is slit on the outermost side; and in this slit the two pins near *V*, fixed in the Moon's axis, move up and down; one of them being above the inclined plane *Y X*, and the other below it. By this mechanism, the Moon *V* moves round the Earth *T* in the inclined orbit *q*, parallel to the plane of the ring *Y X*;

of which the descending node is at X, and the ascending node opposite to it, but hid by the supporter X 2.

The small wheel E turns the large wheels D and F, of equal diameters, by cat-gut strings crossing between them: and the axes of these two wheels are cranked at G and H, above the plate B. The upright stems of these cranks going through the plate C, carry it over and over the fixed plate B, with a motion which carries the Earth U round the Sun T, keeping the Earth's axis always parallel to itself, or still inclining towards the left hand of the plate; and shewing the vicissitudes of seasons, as described in the tenth chapter. As the Earth goes round the Sun, the pinion k goes round the wheel i; for the axis of k never touches the fixed plate B, but turns on a wire fixed into the plate C.

On the top of the crank G is an index L, which goes round the circle m 2 in the time that the Earth goes round the Sun, and points to the days of the months; which, together with the names of the seasons, are marked in this circle.

This index has a small grooved wheel L fixed upon it, round which, and the plate Z, goes a cat-gut string crossing between them; and by this means the Moon's inclined plane Y X, with its nodes, is turned backward, for shewing the times and returns of eclipses, § 319, 320.

The following parts of this machine must be considered as distinct from those already described

Towards the right hand let S be the Earth hung on the wire r, which is fixed into the plate B; and let O be the Moon fixed on the axis M, and turning round within the cap P, in which, and in the plate C, the crooked wire Q is fixed. On the axis M is also fixed the index K, which goes round a circle h 2, divided into 29½ equal parts, which are the days of the Moon's age: but, to avoid confusion in the scheme, it is only marked with the numeral figures 1 2 3 4, for the quarters. As the crank H carries this moon round the Earth S in the orbit t, she shews all her phases by means of the cap P for the different days of her age, which are shewn by the index K; this index, turning just as the moon O does, demonstrates her turning round her axis, as she still keeps the same side towards the Earth S, § 262.

At the other end of the plate C, a moon N goes round an Earth R in the orbit p. But this moon's axis is stuck fast into

the plate *C* at *S* 2, so that neither moon nor axis can turn round; and, as this moon goes round her Earth, she shews herself all round to it; which proves, that if the Moon was seen all round from the Earth in a lunation, she could not turn round her axis.

N. B. If there were only the two wheels *D* and *F*, with a cat-gut string over them, but not crossing between them, the axis of the Earth *U* would keep its parallelism round the Sun *T*, and shew all the seasons, as I sometimes make these machines: and the moon *O* would go round the earth *S*, shewing her phases as above; as likewise would the moon *N* round the earth *R*; but then, neither could the diurnal motion of the earth *U* on its axis be shewn, nor the motion of the moon *V* round the Earth.

399. In the year 1746, I contrived a very simple machine, and described its performance in a small treatise upon the phenomena of the harvest Moon, published in the year 1747. I improved it soon after, by adding another wheel, and called it *The Calculator*. It may be easily made by any person who has a mechanical genius. The Calculator.

The great flat ring supported by twelve pillars, and on which the twelve signs, with their respective degrees, are laid down, is the ecliptic; nearly in the centre of it is the Sun *S*, supported by the strong crooked wire *I*; and from the Sun proceeds a wire *W*, called the *Solar Ray*, pointing towards the centre of the Earth *E*, which is furnished with a moveable horizon *H*, together with a brazen meridian, and quadrant of altitude. *R* is a small ecliptic, whose plane coincides with that of the great one, and has the like signs and degrees marked upon it. It is supported by two wires *D* and *D*, which are put into the plate *P P*, but may be taken off at pleasure. As the Earth goes round the Sun, the signs of this small circle keep parallel to themselves, and to those of the great ecliptic. When it is taken off, and the solar ray *W* drawn farther out, so as almost to touch the horizon *H*, or the quadrant of altitude, the horizon being rectified to any given latitude, and the Earth turned round its axis by hand, the point of the wire *W* shews the Sun's declination in passing over the graduated brass meridian, and his height at any given time upon the quadrant of altitude, together with his azimuth, or Plate VIII. Fig. 1. The Calculator shews the Sun's altitude, azimuth, amplitude, rising and setting;

point of bearing upon the horizon at that time; and likewise his amplitude, and time of rising and setting by the hour index, for any day of the year that the annual index *U* points to in the circle of months below the Sun. *M* is a solar index, or pointer, supported by the wire *L* which is fixed into the knob *K*: the use of this index is to shew the Sun's place in the ecliptic every day in the year; for it goes over the signs and degrees as the index *U* goes over the months and days; or rather, as they pass under the index *U*, in moving the cover plate with the Earth and its furniture round the Sun; for the index *U* is fixed tight on the immoveable axis in the centre of the machine. *K* is a knob or handle for moving the Earth round the Sun, and the Moon round the Earth.

and also the seasons. As the Earth is carried round the Sun, its axis constantly keeps the same oblique direction, or is parallel to itself, § 48, 202, shewing thereby the different lengths of days and nights at different times of the year, with all the various seasons. And, in one annual revolution of the Earth, the moon *M* goes 12⅓ times round it from change to change, having an occasional provision for shewing her different phases. The lower end of the Moon's axis bears by a small friction wheel upon the inclined plane *T*, which causes the Moon to rise above, and sink below the ecliptic *R* in every lunation; crossing it in her nodes, which shift backward through all the signs and degrees of the said ecliptic, by the retrograde motion of the inclined plane *T*, in 18 years and 225 days. On this plane, the degrees and parts of the Moon's north and south latitude are laid down from both the nodes, one of which, viz. the descending node, appears at 0, by *D N* above *B*; the other node being hid from sight on this plane by the plate *P P*; and from both nodes, at proper distances, as in the other orrery, the limits of eclipses are marked, and all the solar and lunar eclipses are shewn in the same manner, for any given year within the limits of 6000, either before or after the Christian era. On the plate that covers the wheel-work, under the Sun *S*, and round the knob *K*, are astronomical tables, by which the machine may be rectified to the beginning of any given year within these limits, in three or four minutes of time; and when once set right, may be turned backward for 300 years past, or forward for as many to come, without requiring any new recti-

It shews the Moon's phases,

and the eclipses of the Sun and Moon.

fication. There is a method for its adding up the 29th of February every fourth year, and allowing only 28 days to that month for every other three: but all this being performed by a particular manner of cutting the teeth of the wheels, and dividing the month circle, too long and intricate to be described here, I shall only shew how these motions may be performed near enough for common use, by wheels with grooves and catgut strings round them; only here I must put the operator in mind, that the grooves are to be made sharp (not round) bottomed, to keep the strings from slipping.

The Moon's axis moves up and down in the socket *N* fixed into the bar *O* (which carries her round the Earth), as she rises above, or sinks below the ecliptic: and immediately below the inclined plane *T*, is a flat circular plate (between *Y* and *T*), on which the different eccentricities of the Moon's orbit are laid down: and likewise her mean anomaly and elliptic equation, by which her true place may be very nearly found at any time. Below this apogee plate, which shews the anomaly, &c. is a circle *Y* divided into $29\frac{1}{2}$ equal parts, which are the days of the Moon's age; and the forked end *A* of the index *A B* (Fig. 2), may be put into the apogee part of this plate; there being just such another index put into the inclined plane *T* at the ascending node; and then the curved points *B* of these indexes shew the direct motion of the apogee, and retrograde motion of the nodes through the ecliptic *R*, with their places in it at any given time. As the moon *M* goes round the Earth *E*, she shews her place every day in the ecliptic *R*, and the lower end of her axis shews her latitude and distance from her node on the inclined plane *T*, also her distance from her apogee and perigee, together with her mean anomaly, the then eccentricity of her orbit, and her elliptic equation, all on the apogee plate, and the day of her age in the circle *Y* of $29\frac{1}{2}$ equal parts, for every day of the year pointed out by the annual index *U* in the circle of months.

Plate VIII. Fig. 2. The Calculator shews the motion of the Moon's apogee and nodes, her place in the ecliptic, &c.

Having rectified the machine by the tables for the beginning of any year, move the Earth and Moon forward by the knob *K*, until the annual index comes to any given day of the month; then stop, and not only all the above phenomena may be shewn for that

and her declination, altitude, azimuth, &c.

day, but also, by turning the Earth round its axis, the declination, azimuth, amplitude, altitude of the Moon at any hour, and the times of her rising and setting, are shewn by the horizon, quadrant of altitude, and hour-index. And in moving the Earth round the Sun, the days of all the new and full moons, and eclipses in any given year, are shewn. The phenomena of the harvest Moon, and those of the tides, by such a cap as that in Plate IX, Fig. 10, put upon the Earth and Moon, together with the solution of many problems not here related, are made conspicuous.

Method of constructing the Calculator. The easiest, though not the best way, that I can instruct any mechanical person to make the wheel-work of such a machine, is as follows: which is the way that I made it, before I thought of numbers exact enough to make it worth the trouble of cutting teeth in the wheels.

Plate VIII. Fig. 3. Fig. 3d of Plate VIII, is a section of this machine; in which *A B C D* is a frame of wood held together by four pillars at the corners, whereof two appear at *A C* and *B D*. In the lower plate *C D* of this frame, are three small friction wheels, at equal distances from each other; two of them appearing at *e* and *e*. As the frame is moved round, these wheels run upon the fixed bottom plate *E E*, which supports the whole work.

In the centre of this last-mentioned plate, is fixed the upright axis *G F F f*, and on the same axis is fixed the wheel *H H H*, in which are four grooves, *I*, *X*, *k*, *L*, of different diameters. In these grooves are cat-gut strings, going also round the separate wheels *M*, *N*, *O*, and *P*.

The wheel *M* is fixed on a solid spindle or axis, the lower pivot of which turns at *R* in the under plate of the moveable frame *A B C D*; and on the upper end of this axis is fixed the plate *o o* (which is *P P*, under the Earth, in Fig. 1), and to this plate is fixed, at an angle of $23\frac{1}{2}$ degrees inclination, the dial plate below the Earth *T*; on the axis of which, the index *q* is turned round by the Earth. This axis, together with the wheel *M*, and plate *o o*, keep their parallelism in going round the Sun *S*.

On the axis of the wheel *M* is a moveable socket, on which the small wheel *N* is fixed, and on the upper end of this socket is put on tight (but so as it may be occasionally turned by hand), the bar *Z Z*, (viz. the bar *O* in Fig. 1), which carries

the Moon *m* round the Earth *T*, by the socket *n*, fixed into the bar. As the Moon goes round the Earth, her axis rises and falls in the socket *n*; because, on the lower end of her axis, which is turned inward, there is a small friction wheel *s* running on the inclined plane *X* (which is *T* in fig. 1), and so causes the Moon alternately to rise above and sink below the little ecliptic *VV* (*R* in Fig 1), in every lunation.

On the socket or hollow axis of the wheel *N*, there is another socket, on which the wheel *O* is fixed; and the Moon's inclined plane *X* is put tightly on the upper end of this socket, not on a square, but on a round, that it may be occasionally set by hand without wrenching the wheel or axle.

Lastly, on the hollow axis of the wheel *O* is another socket, on which is fixed the wheel *P*, and on the upper end of this socket is put on tightly the apogee plate *Y* (that immediately below *T* in Fig. 1). All these axles turn in the upper plate of the moveable frame at *Q*; which plate is covered with the thin plate *cc* (screwed to it), whereon are the fore-mentioned tables and month circle in Fig. 1.

The middle part of the thick fixed wheel *HHH*, is much broader than the rest of it, and comes out between the wheels *M* and *O* almost to the wheel *N*. To adjust the diameters of the grooves of this fixed wheel to the grooves of the separate wheels *M*, *N*, *O*, and *P*, so that they may perform their motions in the proper times, the following method must be observed.

The groove of the wheel *M*, which keeps the parallelism of the Earth's axis, must be precisely of the same diameter as the lower groove *I* of the fixed wheel *HHH*; but, when this groove is so well adjusted as to shew, that in ever so many annual revolutions of the Earth, its axis keeps its parallelism, as may be observed by the solar ray *W* (Fig. 1) always coming precisely to the same degree of the small ecliptic *R* at the end of every annual revolution, when the index *M* points to the like degree in the great ecliptic; then, with the edge of a thin file, give the groove of the wheel *M* a small rub all round, and, by that means lessening the diameter of the groove, perhaps about the 20th part of a hair's breadth, it will cause the Earth to show the precession of the equinoxes; which, in many annual revolutions, will begin to be sensible, as the Earth's axis deviates slowly from its parallelism, § 246, towards the antecedent signs of the ecliptic.

Method of adjusting the diameters of the wheels.

The diameter of the groove of the wheel *N*, which carries the Moon round the Earth, must be to the diameter of the groove *X*, as a lunation is to a year; that is, as $29\frac{1}{2}$ to $365\frac{1}{4}$.

The diameter of the groove of the wheel *O*, which turns the inclined plane *X* with the Moon's nodes backward, must be to the diameter of the groove *k*, as 20 to $18\frac{225}{365}$. And,

Lastly, the diameter of the groove of the wheel *P*, which carries the Moon's apogee forward, must be to the diameter of the groove *L* as 70 to 62.

But, after all this nice adjustment of the grooves to the proportional times of their respective wheels turning round, and which seems to promise very well in theory, there will still be found a necessity of a farther adjustment by hand; because proper allowance must be made for the diameters of the cat-gut strings; and the grooves must be so adjusted by hand, as, that in the time the Earth is moved once round the Sun, the Moon must perform 12 synodical revolutions round the Earth, and be almost 11 days old in her 13th revolution. The inclined plane, with its nodes, must go once round backward through all the signs and degrees of the small ecliptic in 18 annual revolutions of the Earth, and 225 days over. And the apogee plate must go once round forward, so that its index may go over all the signs and degrees of the small ecliptic in eight years (or so many annual revolutions of the Earth), and 312 days over.

N. B. The string which goes round the grooves *X* and *N* for the Moon's motion, must cross between these wheels; but all the rest of the strings go in their respective grooves, *I M*, *k O*, and *L P*, without crossing

The Cometarium. Plate IV. Fig. 4.

400. The COMETARIUM. This curious machine shews the motion of a comet or eccentric body moving round the Sun, describing equal areas in equal times, § 152, and may be so contrived as to shew such a motion for any degree of eccentricity. It was invented by the late Dr. Desaguliers.

The dark elliptical groove round the letters *a b c d e f g h i k l m* is the orbit of the comet *Y*: this comet is carried round in the groove, according to the order of letters, by the wire *W* fixed in the Sun *S*, and slides on the wire as it approaches nearer to or recedes farther from the Sun, be-

ing nearest of all in the perihelion *a*, and farthest in the aphelion *g*. The areas *a S b*, *b S c*, *c S d*, &c. or contents of these several triangles, are all equal; and in every turn of the winch *N* the comet *Y* is carried over one of these areas: consequently, in as much time as it moves from *f* to *g*, or from *g* to *h*, it moves from *m* to *a*, or from *n* to *b*; and so of the rest, being quickest of all at *a*, and slowest at *g*. Thus, the comet's velocity in its orbit continually decreases from the perihelion *a* to to the aphelion *g*; and increases in the same proportion from *g* to *a*.

The elliptic orbit is divided into 12 equal parts or signs, with their respective degrees, and so is the circle *n o p q r s t n*, which represents a great circle in the heavens, and to which the comet's motion is referred by a small knob on the point of the wire *W*. Whilst the comet moves from *f* to *g* in its orbit, it appears to move only about five degrees in this circle, as is shewn by the small knob on the end of the wire *W*; but in the like time, as the comet moves from *m* to *a*, or from *a* to *b*, it appears to describe the large space *t n* or *n o* in the heavens, either of which spaces contains 120 degrees, or four signs. Were the eccentricity of its orbit greater, the greater still would be the difference of its motion, and *vice versa*.

A B C D E F G H I K L M A is a circular orbit for showing the equal motion of a body round the Sun *S*, describing equal areas *A S B*, *B S C*, &c. in equal times with those of the body *Y* in its elliptical orbit above mentioned; but with this difference, that the circular motion describes the equal arcs *A B*, *B C*, &c. in the same equal times that the elliptical motion describes the unequal arcs *a b*, *b c*, &c.

Now, suppose the two bodies *Y* and 1 to start from the points *a* and *A* at the same moment of time, and each having gone round its respective orbit, to arrive at these points again at the same instant, the body *Y* will be forwarder in its orbit than the body 1 all the way from *a* to *g*, and from *A* to *G*; but 1 will be forwarder than *Y* through all the other half of the orbit; and the difference is equal to the equation of the body *Y* in its orbit. At the points *a*, *A*, and *g*, *G*, that is, in the perihelion and aphelion, they will be equal; and then the equation vanishes. This shews why the equation of a body moving in an elliptic orbit, is added to the mean or supposed circular motion from the perihelion to the aphelion, and subtracted from the aphelion to the perihelion, in bodies moving round the Sun, or

from the perigee to the apogee, and from the apogee to the perigee in the Moon's motion round the Earth, according to the precepts in the 353d article; only we are to consider, that when motion is turned into time, it reverses the titles in the table of *the Moon's elliptic equation.*

Plate IV. Fig. 5. This motion is performed in the following manner by the machine. *A B C* is a wooden bar (in the box containing the wheel-work) above which are the wheels *D* and *E*; and below it the elliptic plates *F F* and *G G*, each plate being fixed on an axis in one of its foci, at *E* and *K*, and the wheel *E* is fixed on the same axis with the plate *F F*. These plates have grooves round their edges precisely of equal diameters to one another, and in these grooves is the cat-gut string *g g*, *g g*, crossing between the plates at *h*. On *H* (the axis of the handle or winch *N* in Fig. 4th) is an endless screw in Fig. 5, working in the wheels *D* and *E*, whose number of teeth being each equal to the number of lines *a S*, *b S*, *c S*, &c. in Fig. 4, they turn round their axes in equal times to one another, and to the motion of the elliptic plates. For, the wheels *D* and *E* having equal numbers of teeth, the plate *F F*, being fixed on the same axis with the wheel *E*, and the plate *F F* turning the equally large plate *G G* by a cat-gut string round them both, they must all go round their axis in as many turns of the handle *N* as either of the wheels has teeth.

It is easy to see, that the end *h* of the elliptical plate *F F* being farther from its axis *E* than the opposite end *i* is, must describe a circle so much the larger in proportion; and must therefore move through so much more space in the same time; and for that reason the end *h* moves so much faster than the end *i*, although it goes no sooner round the centre *E*. But then, the quick moving end *h* of the plate *F F* leads about the short end *h K* of the plate *G G* with the same velocity; and the slow moving end *i* of the plate *F F* coming half round as to *B*, must then lead the long end *k* of the plate *G G* as slowly about: so that the elliptical plate *F F* and its axis *E* move uniformly and equally quick in every part of its revolution; but the elliptical plate *G G*, together with its axis *K*, must move very unequally in different parts of its revolution; the difference being always inversely as the distance of any point of the circumference of *G G* from its axis at *K*; or in other words, instance in two points, if the distance *K k* be four, five, or

six times as great as the distance *K h*, the point *h* will move in that position four, five, or six times as fast as the point *k* does: when the plate *G G* has gone half round: and so on for any other eccentricity or difference of the distance *K k* and *K h*. The tooth *i* on the plate *F F* falls in between the two teeth at *k* on the plate *G G*, by which means the revolution of the latter is so adjusted to that of the former that they can never vary from one another

On the top of the axis of the equally moving wheel *D*, in Fig 5th, is the Sun *S* in Fig. 4th: which Sun, by the wire *Z* fixed to it, carries the ball 1 round the circle *A B C D*, &c. with an equable motion, according to the order of the letters: and on the top of the axis *K* of the unequally moving ellipsis *G G*, in Fig. 5th, is the Sun *S* in Fig. 4th, carrying the ball *Y* unequally round in the elliptical groove *a b c d*, &c N. B. This elliptical groove must be precisely equal and similar to the verge of the plate *G G*, which is also equal to that of *F F*. Fig. 4.

In this manner, machines may be made to shew the true motion of the Moon about the Earth, or of any planet about the Sun, by making the elliptical plates of the same eccentricities in proportion to the radius, as the orbits of the planets are, whose motions they represent; and so, their different equations in different parts of their orbits may be made plain to sight: and clearer ideas of these motions and equations acquired in half an hour, than could be gained from reading half a day about such motions and equations.

401. The IMPROVED CELESTIAL GLOBE. On the north pole of the axis, above the hour-circle, is fixed an arch *M K H* of 23½ degrees; and at the end *H* is fixed an upright pin *H G*, which stands directly over the north pole of the ecliptic, and perpendicular to that part of the surface of the globe. On this pin are two moveable collets at *D* and *H*, to which are fixed the quadrantal wires *N* and *O*, having two little balls on their ends for the Sun and Moon, as in the figure. The collet *D* is fixed to the circular plate *F*, whereon the 29½ days of the Moon's age are engraven, beginning just under the Sun's wire *N*; and as this wire is moved round the globe, the plate *F* The improved Celestial Globe. Plate III. Fig. 3.

turns round with it. These wires are easily turned, if the screw *G* be slackened; and when they are set to their proper places, the screw serves to fix them there so, that in turning the ball of the globe, the wires with the Sun and Moon go round with it; and these two little balls rise and set at the same times, and on the same points of the horizon, for the day to which they are rectified, as the Sun and Moon do the heavens.

Because the Moon keeps not her course in the ecliptic (as the Sun appears to do) but has a declination of 5⅓ degrees on each side from it in every lunation, § 317, her ball may be screwed as many degrees to either side of the ecliptic as her latitude or declination from the ecliptic amounts to at any given time, and for this purpose *S* is a small piece of pasteboard, of which the curved edge at *S* is to be set upon the globe at right angles to the ecliptic, and the dark line over *S* to stand upright upon it. From this line, on the convex edge, are drawn the 5⅓ degrees of the Moon's latitude on both sides of the ecliptic; and when this piece is set upright on the globe, its graduated edge reaches to the Moon on the wire *O*, by which means she is easily adjusted to her latitude found by an ephemeris.

The horizon is supported by two semicircular arches, because pillars would stop the progress of the balls when they go below the horizon in an oblique sphere.

To rectify the improved globe. *To rectify this globe.* Elevate the pole to the latitude of the place; then bring the Sun's place in the ecliptic for the given day to the brazen meridian, and set the hour-index to XII at noon, that is, to the upper XII on the hour-circle; keeping the globe in that situation, slacken the screw *G*, and set the Sun directly over his place on the meridian; which done, set the Moon's wire under the number that expresses her age for that day on the plate *F*, and she will then stand over her place in the ecliptic, and shew what constellation she is in. Lastly, fasten the screw *G*, and laying the curved edge of the pasteboard *S* over the ecliptic below the Moon, adjust the moon to her latitude over the graduated edge of the pasteboard; and the globe will be rectified.

Method of using it. Having thus rectified the globe turn it round, and observe on what points of the horizon the Sun and Moon balls rise and set, for these agree with the points of the compass on which the Sun and Moon rise and set in the hea-

vens on the given day: and the hour-index shews the times of their rising and setting; and likewise the time of the Moon's passing over the meridian.

This simple apparatus shews all the varieties that can happen in the rising and setting of the Sun and Moon; and makes the fore-mentioned phenomena of the harvest Moon (Chap xvi), plain to the eye. It is also very useful in reading lectures on the globes, because a large company can see the Sun and Moon go round, rising above and setting below the horizon at different times, according to the seasons of the year; and making their appulses to different fixed stars. But in the usual way, where there is only the places of the Sun and Moon in the ecliptic to keep the eye upon, they are easily lost sight of, unless they be covered with patches.

402. The PLANETARY GLOBES. In this machine, *T* is a terrestrial globe fixed on its axis standing upright on the pedestal *C D E*, on which is an hour-circle, having its index fixed on the axis, which turns somewhat tightly in the pedestal, so that the globe may not be liable to shake; to prevent which, the pedestal is about two inches thick, and the axis goes quite through it, bearing on a shoulder. The globe is hung in a graduated brazen meridian, much in the usual way; and the thin plate *N E*, is a moveable horizon, graduated round the outer edge, for shewing the bearings and amplitudes of the Sun, Moon, and planets. The brazen meridian is grooved round the outer edge; and in this groove is a slender semicircle of brass, the ends of which are fixed to the horizon in its north and south points: this semicircle slides in the groove as the horizon is moved in rectifying it for different latitudes. To the middle of the semi-circle is fixed a pin, which always keeps in the zenith of the horizon, and on this pin, the quadrant of altitude *q* turns; the lower end of which, in all positions, touches the horizon as it is moved round the same. This quadrant is divided into 90 degrees from the horizon to the zenithal pin on which it is turned, at 90. The great flat circle or plate *A B* is the ecliptic, on the outer edge of which the signs and degrees are laid down; and every fifth degree is drawn through the rest of the surface of this plate towards its centre. On this plate are seven grooves, to which seven little balls are adjusted by sliding wires, so that they are easily moved in the grooves, without danger of start-

The Planetary Globes. Plate VIII. Fig. 4.

ing out of them. The ball next the terrestrial globe is the Moon, the next without it is Mercury, the next Venus, the next the Sun, then Mars, then Jupiter, and lastly Saturn; and in order to know them, they are separately stamped with the following characters: ☽, ☿, ♀, ☉, ♂, ♃, ♄. This plate or ecliptic is supported by four strong wires, having their lower ends fixed into the pedestal, at *C*, *D*, and *E*, the fourth being hid by the globe. The ecliptic is inclined $23\frac{1}{2}$ degrees to the pedestal, and is therefore properly inclined to the axis of the globe which stands upright on the pedestal.

Method of rectifying the Planetary Globe.

To rectify this machine. Set this Sun, and all the planetary balls, to their geocentric places in the ecliptic for any given time, by an ephemeris, then set the north point of the horizon to the latitude of your place on the brazen meridian, and the quadrant of altitude to the south point of the horizon, which done, turn the globe with its furniture till the quadrant of altitude comes right against the Sun, viz. to his place in the ecliptic, and keeping it there, set the hour index to the XII next the letter *C*; and the machine will be rectified, not only for the following problems, but for several others, which the artist may easily find out

PROB. I.—*To find the Amplitudes, Meridian Altitudes, and times of Rising, Culminating, and Setting, of the Sun, Moon, and Planets.*

To find the altitude, amplitude, southing, rising, and setting of the planets.

Turn the globe round eastward, or according to the order of the signs; and as the eastern edge of the horizon comes right against the Sun, Moon, or any planet, the hour index will shew the time of its rising; and the inner edge of the ecliptic will cut its rising amplitude in the horizon. Turn on, and as the quadrant of altitude comes right against the Sun, Moon, or planets, the ecliptic cuts their meridian altitudes in the quadrant, and the hour index shews the time of their coming to the meridian. Continue turning, and as the western edge of the horizon comes right against the Sun, Moon, or planets, their setting amplitudes are cut in the horizon by the ecliptic; and the times of their setting are shewn by the index on the hour circle.

PROB. II.—*To find the Altitude and Azimuth of the Sun, Moon, and Planets, at any time of their being above the Horizon.*

Turn the globe till the index comes to the given time in the hour circle; then keep the globe steady, and moving the quadrant of altitude to each planet respectively, the edge of the ecliptic will cut the planet's mean altitude on the quadrant, and the quadrant will cut the planet's azimuth, or point of bearing, on the horizon.

To find the altitude and azimuth of the planets.

PROB. III.—*The Sun's Altitude being given at any time either before or after Noon, to find the Hour of the Day, and the Variation of the Compass, in any known Latitude.*

With one hand hold the edge of the quadrant right against the Sun, and, with the other hand, turn the globe westward, if it be in the forenoon, or eastward, if it be in the afternoon, until the Sun's place at the inner edge of the ecliptic cuts the quadrant in the Sun's observed altitude; and then the hour index will point out the time of the day, and the quadrant will cut the true azimuth, or bearing of the Sun for that time: the difference between which, and the bearing shewn by the azimuth compass, shews the variation of the compass in that place of the Earth.

To find the hour of the day, and the variation of the compass.

403. The TRAJECTORIUM LUNARE. This machine is for delineating the paths of the Earth and Moon, shewing what sort of curves they make in the ethereal regions; and was just mentioned in the 266th article. *S* is the Sun, and *E* the Earth, whose centres are 81 inches distant from each other; every inch answering to a million of miles, § 47. *M* is the Moon, whose centre is $\frac{21}{100}$ parts of an inch from the Earth's in this machine, this being in just proportion to the Moon's distance from the Earth, § 52. *A A* is a bar of wood, to be moved by hand round the axis *g*, which is fixed in the wheel *Y*. The circumference of this wheel is to the circumference of the small wheel *L* (below the other end of the bar) as 365¼ days is to 29½; or as a year

The Trajectorium Lunare. Plate VII. Fig. 5.

is to a lunation. The wheels are grooved round their edges, and in the grooves is the cat-gut string *G G* crossing between the wheels at *X*. On the axis of the wheel *L* is the index *F*, in which is fixed the Moon's axis *M* for carrying her round the Earth *E* (fixed on the axis of the wheel *L*) in the time that the index goes round a circle of 29½ equal parts, which are the days of the Moon's age. The wheel *Y* has the months and days of the year all round its limb; and in the bar *A A* is fixed the index *I*, which points out the days of the months answering to the days of the Moon's age, shewn by the index *F*, in the circle of 29½ equal parts at the other end of the bar. On the axis of the wheel *L* is put the piece *D*, below the cock *C*, in which this axis turns round; and in *D* are put the pencils *e* and *m*, directly under the Earth *E* and Moon *M*, so that *m* is carried round *e*, as *M* is round *E*.

Method of using it. Lay the machine on an even floor, pressing gently on the wheel *Y*, to cause its spiked feet (of which two appear at *P* and *P*, the third being supposed to be hid from sight by the wheel) enter a little into the floor to secure the wheel from turning. Then lay a paper about four feet long under the pencils *e* and *m*, cross-ways to the bar: which done, move the bar slowly round the axis *g* of the wheel *Y*; and, as the Earth *E* goes round the Sun *S*, the Moon *M* will go round the Earth with a duly proportioned velocity; and the friction wheel *W* running on the floor will keep the bar from bearing too heavily on the pencils *e* and *m*, which will delineate the paths of the Earth and Moon, as in Fig. 2d, already described at large in § 266, 267. As the index *I* points out the days of the months, the index *F* shews the Moon's age on these days, in the circle of 29½ equal parts. And as this last index points to the different days in its circle, the like numeral figures may be set to those parts of the curves of the Earth's path and Moon's, where the pencil *e* and *m* are at those times respectively, to shew the places of the Earth and Moon. If the pencil *e* be pushed a very little off, as if from the pencil *m*, to about $\frac{1}{40}$ part of their distance, and the pencil *m* pushed as much towards *e* to bring them to the same distance again, though not to the same points of space; then, as *m* goes round *e*, *e* will go as it were round the centre of gravity between the Earth *e* and Moon *m*, § 298: but this motion will not sensibly alter the figure of the Earth's path or the Moon's.

If a pin, as *p*, be put through the pencil *m*, with its head towards that of the pin *q* in the pencil *e*, its head will always keep thereto as *m* goes round *e*, or as the same side of the Moon is still turned to the Earth. But the pin *p*, which may be considered as an equatoreal diameter of the Moon, will turn quite round the point *m*, making all possible angles with the line of its progress, or line of the Moon's path. This is an ocular proof of the Moon's turning round her axis.

404. The TIDE-DIAL. The outside parts of this machine consist of—1, An eight-sided box, on the top of which, at the corners, is shewn the phases of the Moon at the octants, quarters, and full. Within these is a circle of 29½ equal parts, which are the days of the Moon's age reckoned from the Sun at new moon, round to the Sun again. Within this circle is one of 24 hours divided into their respective halves and quarters. 2, A moving elliptical plate, painted blue, to represent the rising of the tides under and opposite to the Moon; and has the words, *high water*, *tide falling*, *low water*, *tide rising*, marked upon it. To one end of this plate is fixed the Moon *M* by the wire *W*, and goes along with it. 3, Above this elliptical plate is a round one, with the points of the compass upon it, and also the names of above 200 places in the large machine (but only 32 in the figure, to avoid confusion) set over those points on which the Moon bears when she raises the tides to the greatest height at these places twice in every lunar day: and to the north and south points of this plate are fixed two indexes *I* and *K*, which shew the times of high-water, in the hour circle, at all these places. 4, Below the elliptical plate are four small plates, two of which project out from below its ends at new and full moon: and so, by lengthening the ellipse, shew the spring tides, which are then raised to the greatest heights by the united attractions of the Sun and Moon, § 302 The other two of these small plates appear at low water when the moon is in her quadratures, or at the sides of the elliptic plate, to shew the neap-tides; the Sun and Moon then acting cross-ways to each other. When any two of these small plates appear, the other two are hid; and when the Moon is in her octants, they all disappear, there being neither spring nor

The Tide-dial.
Plate IX. Fig. 7.

Method of using the Tide-dial.

neap tides at those times. Within the box are a few wheels for performing these motions by the handle or winch *H*..

Turn the handle until the Moon *M* comes to any given day of her age in the circle of 29½ equal parts, and the Moon's wire *W* will cut the time of her coming to the meridian on that day, in the hour circle, the XII under the Sun being mid-day, and the opposite XII midnight; then looking for the name of any given place on the round plate (which makes 29½ rotations whilst the Moon *M* makes only one revolution from the Sun to the Sun again) turn the handle till *that* place comes to the word *high water* under the Moon, and the index which falls among the forenoon hours will shew the time of high water at that place in the forenoon of the given day: then turn the plate half round, till the same place comes to the opposite high water mark, and the index will show the time of high water in the afternoon at that place And thus, as all the different places come successively under and opposite to the Moon, the indexes show the times of high water at them in both parts of the day and when the same places come to the low water marks, the indexes show the times of low water For about three days before and after the times of new and full moon, the two small plates come out a little way from below the high water marks on the elliptical plate, to show that the tides rise still higher about these times: and about the quarters, the other two plates come out a little from under the low water marks towards the Sun and on the opposite side, shewing that the tides of flood rise not then so high, nor do the tides of ebb fall so low, as at other times.

By pulling the handle a little way outward, it is disengaged from the wheel-work, and then the upper plate may be turned round quickly by hand, so that the Moon may be brought to any given day of her age in about a quarter of a minute · and by pushing in the handle, it takes hold of the wheel-work again.

The inside work described. Plate IX. Fig. 8. On *A B*, the axis of the handle *H*, is an endless screw *C*, which turns the wheel *F E D* of 24 teeth round in 24 revolutions of the handle: this wheel turns another, *O N G*, of 48 teeth, and on its axis is the pinion *P Q* of four leaves, which turns the wheel *L K I* of 59 teeth round in 29½ turnings or rotations of the wheel *F E D*, or in 708 revolutions of the handle, which is the num-

ber of hours in a synodical revolution of the Moon. The round plate with the names of places upon it is fixed on the axis of the wheel *F E D;* and the elliptical or tide-plate with the moon fixed to it is upon the axis of the wheel *L K I;* consequently, the former makes $29\frac{1}{2}$ revolutions in the time that the latter makes one. The whole wheel *F E D*, with the endless screw *C*, and dotted part of the axis of the handle *A B*, together with the dotted part of the wheel *O N G*, lie hid below the large wheel *L K I.*

Description of the dial-plate.

Fig. 9th represents the under side of the elliptical or tide-plate *a b c d*, with the four small plates *A B C D, E F G H, I K L M, N O P Q*, upon it: each of which has two slits, as *T T, S S, R R, U U*, sliding on two pins, as *n n* fixed in the elliptical plate. In the four small plates are fixed four pins, at *W, X, Y*, and *Z;* all of which work in an elliptic groove *o o o o* on the cover of the box below the elliptical plate; the longest axis of this groove being in a right line with the sun and full moon. Consequently, when the Moon is in conjunction or opposition, the pins *W* and *X* thrust out the plates *A B C D* and *I K L M* a little beyond the ends of the elliptic plate at *d* and *b*, to *f* and *e;* whilst the pins *Y* and *Z* draw in the plates *E F G H* and *N O P Q* quite under the elliptic plate to *g* and *h*. But, when the Moon comes to her first or third quarter, the elliptic plate lies across the fixed elliptic groove in which the pins work; and therefore the end plates *A B C D* and *I K L M* are drawn in below the great plate, and the other two plates *E F G H* and *N O P Q* are thrust out beyond it to *a* and *c*. When the Moon is in her octants, the pins *W, X, Y, Z*, are in the parts *o, o, o, o*, of the elliptic groove, which parts are at a mean between the greatest and least distances from the centre *q*, and then all the four small plates disappear below the great one.

The Eclipsareon. Plate XIII.

405. The ECLIPSAREON. This piece of mechanism exhibits the time, quantity, duration, and progress of solar eclipses, at all parts of the Earth.

The principal parts of this machine are, 1, A terrestrial globe *A* turned round its axis *B* by the handle or winch *M;* the axis *B* inclines $23\frac{1}{2}$ degrees, and has an index which goes round the hour-circle *D* in each rotation of the globe. 2, A circular plate *E*, on the limb of which the months

and days of the year are inserted. This plate supports the globe, and gives its axis the same position to the Sun, or to a candle properly placed, that the Earth's axis has to the Sun upon any day of the year, § 338, by turning the plate till the given day of the month comes to the fixed pointer, or annual index *G*. 3, A crooked wire *F*, which points towards the middle of the Earth's enlightened disc at all times, and shews to what place of the Earth the Sun is vertical at any given time. 4, A penumbra, or thin circular plate of brass *I* divided into 12 digits by 12 concentric circles, which represent a section of the Moon's penumbra, and is proportioned to the size of the globe; so that the shadow of this plate, formed by the Sun, or a candle placed at a convenient distance, with its rays transmitted through a convex lens to make them fall parallel on the globe, covers exactly all those places upon it that the Moon's shadow and penumbra do on the Earth so that the phenomena of any solar eclipse may be shewn by this machine with candle-light almost as well as by the light of the Sun 5, An upright frame *H H H H*, on the sides of which are scales of the Moon's latitude or declination from the ecliptic To these scales are fitted two sliders *K* and *K*, with indexes for adjusting the penumbra's centre to the Moon's latitude, according as it is north or south, ascending or descending 6, A solar horizon *C*, dividing the enlightened hemisphere of the globe from that which is in the dark at any given time, and shewing at what places the general eclipse begins and ends with the rising or setting Sun 7, A handle *M*, which turns the globe round its axis by wheel-work, and at the same time moves the penumbra across the frame by threads over the pullies, *L*, *L*, *L*, with a velocity duly proportioned to that of the Moon's shadow over the Earth, as the Earth turns on its axis. And as the Moon's motion is quicker or slower, according to her different distances from the Earth, the penumbral motion is easily regulated in the machine by changing one of the pullies.

To rectify the Eclipsareon. 406. *To rectify the machine for use.* The true time of new Moon and her latitude being known by the foregoing precepts, § 353, *et seq.* if her latitude exceeds the number of minutes or divisions on the scales (which are on the side of the frame hid from view in the figure of the machine), there can be no eclipse of the Sun at that conjunction; but if it does not, the Sun will be eclipsed to some places of

the Earth; and, to shew the times and various appearances of the eclipse at those places, proceed in order as follows.

407. *To rectify the machine for performing by the light of the Sun.* 1, Move the sliders *K K* till their indexes point to the Moon's latitude on the scales, as it is north or south ascending or descending, at that time. 2, Turn the month-plate *E* till the day of the given new moon comes to the annual index *G*. 3, Unscrew the collar *N* a little on the axis of the handle, to loosen the contiguous socket on which the threads that move the penumbra are wound; and set the penumbra by hand till its centre comes to the perpendicular thread in the middle of the frame; which thread represents the axis of the ecliptic. 4, Turn the handle till the meridian of London on the globe comes just under *P*, the point of the crooked wire *F*; then stop, and turn the hour-circle *D* by hand till XII at noon comes to its index, and set the penumbra's middle to the thread. 5, Turn the handle till the hour-index points to the time of new moon in the circle *D*; and holding it there, screw fast the collar *N*. Lastly, Elevate the machine till the Sun shines through the sight holes in the small upright plates, *O*, *O*, on the pedestal; and the whole machine will be rectified

To rectify the Eclipsareon for the light of the Sun.

408. *To rectify the machine for shewing by candle-light.* Proceed in every respect as above, except in that part of the last paragraph where the Sun is mentioned; instead of which place a candle before the machine, about four yards from it, so as the shadow of intersection of the cross threads in the middle of the frame may fall precisely on that part of the globe below *P* the point of the crooked wire: then, with a pair of compasses, take the distance between the penumbra's centre and intersection of the threads; and equal to that distance set the candle higher or lower, as the penumbra's centre is above or below the said intersection. Lastly, Place a large convex lens between the machine and candle, so that the candle may be in the focus of the lens, and then the rays will fall parallel, and cast a strong light on the globe.

To rectify the Eclipsareon for candle-light.

These things being done, turn the handle backward, until the penumbra almost touches the side *H F* of the frame; then turning it gradually forward, observe the following phenomena:—1, Where the eastern edge of the

Method of using the Eclipsareon.

shadow of the penumbral plate *I* first touches the globe at the solar horizon, those who inhabit the corresponding part of the Earth see the eclipse begin on the uppermost edge of the Sun, just at the time of its rising. 2, In that place where the penumbra's centre first touches the globe, the inhabitants have the Sun rising upon them centrally eclipsed. 3, When the whole penumbra just falls upon the globe, its western edge at the solar horizon touches and leaves the place where the eclipse ends at sun-rise on his lowermost edge Continue turning, and, 4, The cross lines in the centre of the penumbra will go over all those places on the globe when the Sun is centrally eclipsed 5, When the eastern edge of the shadow touches any place of the globe, the eclipse begins there; when the vertical line in the penumbra comes to any place, then is the greatest obscuration at that place; and when the western edge of the penumbra leaves the place, the eclipse ends there, the times of all which are shewn on the hour-circle, and from the beginning to the end, the shadows of the concentric penumbral circles shew the number of digits eclipsed at all the intermediate times 6, When the eastern edge of the penumbra leaves the globe at the solar horizon *C*, the inhabitants see the Sun beginning to be eclipsed on his lowermost edge at its setting 7, Where the penumbra's centre leaves the globe, the inhabitants see the Sun set centrally eclipsed And, lastly, where the penumbra is wholly departing from the globe, the inhabitants see the eclipse ending on the uppermost part of the Sun's edge, at the time of its disappearing in the horizon

The Eclipsareon also shews the time of her rising and setting, the duration of twilight, &c.

409 If any given day of the year on the plate *E* be set to the annual-index *G*, and the handle turned till the meridian of any place comes under the point of the crooked wire, and then the hour-circle *D* set by the hand till XII comes to its index; in turning the globe round by the handle, when the said place touches the eastern edge of the hoop or solar horizon *C*, the index shews the time of sun setting at that place; and when the place is just coming out from below the other edge of the hoop *C*, the index shews the time when the evening twilight ends to it. When the place has gone through the dark part *A*, and comes about so as to immerge under the back of the hoop *C* on the other side, the index shews the time when the morning twilight

begins; and when the same place is just coming out from below the edge of the hoop next the frame, the index points outs the time of sun-rising. And thus, the times of sun-rising and setting are shewn at all places in one rotation of the globe, for any given day of the year: and the point *P* of the crooked wire *F* shews all the places over which the Sun passes vertically on that day.

CHAP. XXIII

THE METHOD OF FINDING THE DISTANCES OF THE PLANETS FROM THE SUN.

ART I.—*Concerning Parallaxes, and their Use in general.*

410 THE[1] approaching transit of Venus over the Sun has justly engaged the attention of astronomers, as it is a phenomenon seldom seen, and as the parallaxes of the Sun and planets, and their distance from one another, may be found with greater accuracy by it, than by any other method yet known.

The transit of Venus useful in finding the parallaxes of the planets.

411. The parallax of the Sun, Moon, or any planet, is the distance between its true and apparent place in the heavens. The true place of any celestial object, referred to the starry heaven, is that in which it would appear if seen from the centre of the Earth; the apparent place is that in which it appears as seen from the Earth's surface.

Explanation of parallax.

To explain this, let *A B D H* be the Earth (Fig. 1; of Plate XIV), *C* its centre, *M* the Moon, and *Z X R* an arc of the starry heaven. To an observer at *C* (supposing the Earth to be transparent) the Moon *M* will appear at *U*, which is her true place referred to the starry firmament: but at the same instant, to an observer at *A* she will appear at *u*, below her true place as among the stars. The angle *A M C* is called the Moon's parallax, and is equal to the

Plate XIV. Fig. 1.

[1] The whole of this Dissertation was published in the beginning of the year 1761, before the time of the transit, except the 7th and 8th articles, which have been added since that time.

opposite angle *U M u*, (Playfair's Eucl. B. i, Prop. 15.) whose measure is the celestial arc *U u*. The whole Earth is but a point if compared with its distance from the fixed stars; and therefore we consider the stars as having no parallax at all.

The parallax of any body increases as its altitude diminishes.

412. The nearer the object is to the horizon, the greater is its parallax; the nearer it is to the zenith, the less. In the horizon it is greatest of all, in the zenith it is nothing.—Thus let *A L t* be the sensible horizon of an observer at *A*; to him the Moon at *L* is in the horizon, and her parallax is the angle *A L C*, under which the Earth's semidiameter *A C* appears as seen from her This angle is called the Moon's horizontal parallax, and is equal to the opposite angle *T L t*, whose measure is the arc *T t* in the starry heaven. As the Moon rises higher and higher to the points *M*, *N*, *O*, *P*, in her diurnal course, the parallactic angles *U M u*, *X N x*, *Y O y*, diminish, and so do the arcs *U u*, *X x*, *Y y*, which are their measures, until the Moon comes to *P*; and then she appears in the zenith *Z* without any parallax, her place being the same as seen from *A* on the Earth's surface, and from *C* its centre.

How to find the Moon's distance from her parallax.

413. If the observer at *A* could take the true measure or quantity of the parallactic angle *A L C*, he might thereby find the Moon's distance from the centre of the Earth. For then, in the plain triangle *L A C*, the side *A C*, which is the Earth's semidiameter, the angle *A L C*, which is the Moon's horizontal parallax, and the right angle *C A L*, would be given. Therefore, by trigonometry, as the tangent of the parallactic angle *A L C* is to radius, so is the Earth's semidiameter *A C* to the Moon's distance *C L* from the Earth's centre *C* (Playfair's Eucl. Trigon. Prop. 1). But because we consider the Earth's semidiameter as unity, and the logarithm of unity is nothing, subtract the logarithmic tangent of the angle *A L C* from radius, and the remainder will be the logarithm of *C L*, whose number is equal to the number of semidiameters of the Earth by which the Moon is distant from the Earth's centre. Thus, supposing the angle *A L C* of the Moon's horizontal parallax to be 57′. 18″,

From the radius	10.0000000
Subtract the tangent of 57′ 18″	8.2219207
And there will remain	1.7780793;

which is the logarithm of 59.99, the number of semidiameters of the Earth, which are equal to the Moon's distance from the Earth's centre. Then 59.99 being multiplied by 3985, the number of miles contained in the Earth's semidiameter, will give 239082 miles for the Moon's distance from the centre of the Earth, by this parallax.

414. But the true quantity of the Moon's horizontal parallax cannot be accurately determined by observing the Moon in the horizon, on account of the inconstancy of the horizontal refractions, which always vary according to the state of the atmosphere; and, at a mean rate, elevate the Moon's apparent place near the horizon half as much more than as her parallax depresseth it. And, therefore, to have her parallax more accurate, astronomers have thought of the following method, which seems to be a very good one, but which has not yet been put in practice.

Method of finding the Moon's parallax.

Let two observers be placed under the same meridian, one in the northern hemisphere, and the other in the southern, at such a distance from each other, that the arc of the celestial meridian included between their two zeniths may be at least 80 or 90 degrees. Let each observer take the distance of the Moon's centre from his zenith, by means of an exceeding good instrument, at the moment of her passing the meridian; add these two zenith-distances of the Moon together, and their excess above the distance between the two zeniths will be the distance between the two apparent places of the Moon. Then, as the sum of the natural sines of the two zenith-distances of the Moon is to radius, so is the distances between her two apparent places to her horizontal parallax: which being found, her distance from the Earth's centre may be found by the analogy mentioned in § 413.

Illustration of this method. Fig. 2.

Thus, in Fig. 2, let *V E C Q* be the Earth, *M* the Moon, and *Z b a x* an arc of the celestial meridian. Let *V* be Vienna, whose latitude *E V* is 48° 20′ north; and *C* the Cape of Good Hope, whose latitude *E C* is 34° 30′ south: both which latitudes we suppose to be accurately determined beforehand by the observers. As these two places are on the same meridian *n V E C s*, and in different hemispheres, the sum of their latitudes 82° 50′ is their distance from

each other. *Z* is the zenith of Vienna, and *z* the zenith of the Cape of Good Hope; which two zeniths are also 82° 50′ distant from each other, in the common celestial meridian *Z z*. To the observer at Vienna, the Moon's centre will appear at *a* in the celestial meridian; and at the same instant, to the observer at the Cape, it will appear at *b*. Now, suppose the Moon's distance *Z a* from the zenith of Vienna to be 38° 1′ 53″, and her distance *z b* from the zenith of the Cape of Good Hope to be 46° 4′ 41″, the sum of these two zenith-distances (*Z a* + *z b*) is 84° 6′ 34″, from which subtract 82° 50′, the distance *Z z* between the zeniths of these two places, and there will remain 1° 16′ 34″, for the arc *b a*, or distance between the two apparent places of the Moon's centre, as seen from *V* and from *C*. Then, supposing the tabular radius to be 10000000, the natural sine of 38° 1′ 53″ (the arc *Z a*) is 6160816, and the natural sine of 46° 4′ 14″ (the arc *z b*) is 7202821, the sum of both these sines is 13363637. Say, therefore, as 13363637 is to 10000000, so is 1° 16′ 34″, to 57′ 18″, which is the Moon's horizontal parallax.

If the two places of observation be not exactly under the same meridian, their difference of longitude must be accurately taken, that proper allowance may be made for the Moon's declination whilst she is passing from the meridian of the one to the meridian of the other.

Relative magnitudes of the Earth and Moon.

415. The Earth's diameter, as seen from the Moon, subtends an angle of double the Moon's horizontal parallax, which being supposed (as above) to be 57′ 18″, or 3438″, the Earth's diameter must be 1° 54′ 36″, or 6876″. When the Moon's horizontal parallax (which is variable on account of the eccentricity of her orbit) is 57′ 18″, her diameter subtends an angle of 31′ 2″, or 1862″: therefore, the Earth's diameter is to the Moon's diameter, as 6876 is to 1862; that is, as 3.69 is to 1.

And since the relative bulks of spherical bodies are as the cubes of their diameters, the Earth's bulk is to the Moon's bulk, as 49.4 is to one.

416. The parallax, and consequently the distance and bulk, any primary planet, might be found in the above manner, if planet was near enough to the Earth, so as to make the ference of its two apparent places sufficiently sensible; but

the nearest planet is too remote for the accuracy required. In order therefore to determine the distances and relative bulks of the planets with any tolerable degree of precision, we must have recourse to a method less liable to error; and this the approaching transit of Venus over the Sun's disc will afford us.

The transit of Venus best fitted for finding the parallaxes of the primary planets.

417. From the time of any inferior conjunction of the Sun and Venus to the next, is 583 days 22 hours 7 minutes. And, if the plane of Venus's orbit were coincident with the plane of the ecliptic, she would pass directly between the Earth and the Sun at each inferior conjunction, and would then appear like a dark round spot on the Sun for about 7 hours and 3 quarters. But Venus's orbit (like the Moon's) only intersects the ecliptic in two opposite points, called its nodes. And therefore one half of it is on the north side of the ecliptic, and the other on the south: on which account, Venus can never be seen on the Sun, but at those inferior conjunctions which happen in or near the nodes of her orbit. At all the other conjunctions, she either passes above or below the Sun; and her dark side being then towards the Earth, she is invisible.—The last time when this planet was seen like a spot on the Sun, was on the 24th of November, old style, in the year 1639.

Art. II.—*Shewing how to find the Horizontal Parallax of Venus by observation, and from thence, by analogy, the Parallax and Distance of the Sun, and of all the Planets from him.*

418. In Fig. 4, of Plate XIV, let *D A B* be the Earth, *V* Venus, and *T S R* the eastern limb of the Sun. To an observer at *B*, the point *t* of that limb will be on the meridian, its place referred to the heaven will be at *E*, and Venus will appear just within it at *S*. But, at the same instant, to an observer at *A*, Venus is east of the Sun, in the right line *A V F*; the point *t* of the Sun's limb appears at *e* in the heavens; and if Venus were then visible, she would appear at *F*. The angle *C V A* is the horizontal parallax of Venus, which we seek; and is equal to the opposite angle *F V E*, whose measure is the arc *F E*. *A S C* is the Sun's horizontal parallax,

Plate XIV. Fig. 4.

equal to the opposite angle *e S E*, whose measure is the arc *e E*: and *F A e* (the same as *V A v*) is Venus's horizontal parallax from the Sun, which may be found by observing how much later in absolute time her total ingress on the Sun is, as seen from *A*, than as seen from *B*, which is the time she takes to move from *V* to *v* in her orbit *O V v*.

419. It appears by the tables of Venus's motion and the Sun's, that at the time of her ensuing transit, she will move 4 minutes of a degree on the Sun's disc in 60 minutes of time; and therefore she will move 4 seconds of a degree in one minute of time.

Now, let us suppose, that *A* is 90 degrees west of *B*, so that when it is noon at *B*, it will be VI in the morning at *A*, that the total ingress as seen from *B* is at 1 minute past XII, but that as seen from *A* it is at 7 minutes 30 seconds past VI: deduct 6 hours for the difference of meridians of *A* and *B*, and the remainder will be 6 minutes 30 seconds for the time by which the total ingress of Venus on the Sun at *S* is later as seen from *A* than as seen from *B* which time being converted into parts of a degree is 26 seconds, or at the arc *F e* of Venus's horizontal parallax from the Sun for, as 1 minute of time is to 4 seconds of a degree, so is 6½ minutes of time to 26 seconds of a degree.

420. The times in which the planets perform their annual revolutions about the Sun are already known by observation From these times, and the universal power of gravity by which the planets are retained in their orbits, it is demonstrable, that if the Earth's mean distance from the Sun be divided into 100000 equal parts, Mercury's mean distance from the Sun must be equal to 38710 of these parts—Venus's mean distance from the Sun, to 72333—Mars's mean distance, 152369—Jupiter's, 520096—and Saturn's, 954006. **Therefore, when the number of miles contained in the mean distance of any planet from the Sun is known, we can, by these proportions, find the mean distance in miles of all the rest.**

421. At the time of the ensuing transit, the Earth's distance from the Sun will be 1015 (the mean distance being here considered as 1000), and Venus's distance from the Sun will be

e mean distance being considered as 723), which differ-

from the mean distances arise from the elliptical figure of

the planets' orbits. Subtract 726 parts from 1015, and there will remain 289 parts for Venus's distance from the Earth at that time.

421. Now, since the horizontal parallaxes of the planets are[a] inversely as their distances from the Earth's centre, it is plain, that as Venus will be between the Earth and the Sun on the day of her transit, and consequently her parallax will be then greater than the Sun's, if her horizontal parallax can be on that day ascertained by observation, the Sun's horizontal parallax may be found, and consequently his distance from the Earth.—Thus, suppose Venus's horizontal parallax should be found to be 36″.3480; then, as the Sun's distance 1015 is to Venus's distance 289, so is Venus's horizontal parallax 36″.3480 to the Sun's horizontal parallax 10″.3493 on the day of her transit. And the difference of these two parallaxes, viz. 25″.9987 (which may be esteemed 26″) will be the quantity of Venus's horizontal parallax from the Sun; which is one of the elements for projecting or delineating her transit over the Sun's disc, as will appear further on.

To find the Sun's horizontal parallax at the time of his mean distance from the Earth, say, as 1000 parts, the Sun's mean distance from the Earth's centre, is to 1015, his distance therefrom on the day of the transit, so is 10″.3493, his horizontal parallax on that day, to 10″.5045, his horizontal parallax at the time of his mean distance from the Earth's centre.

422. The Sun's parallax being thus (or any other way supposed to be) found, at the time of his mean distance from the Earth, we may find his true distance therefrom, in semidiameters of the Earth, by the following analogy. As the sine (or tangent of so small an arc as that) of the Sun's parallax 10″.5045 is to radius, so is unity or the Earth's semidiameter to the number of semidiameters of the Earth that the Sun is distant from its centre, which number, being multiplied by 3985, the num-

[a] To prove this, let *S* be the Sun (Fig. 3), *V* Venus, *A B* the Earth, *C* its centre, and *A C* its semidiameter. The angle *A V C* is the horizontal parallax of Venus, and *A S C* the horizontal parallax of the Sun. But by the property of plane triangles (Playfair's Euclid, Plane Trig. Prop. ii.) as the sine of *A V C* (or of *S V A* its supplement to 180) is to the sine of *A S C*, so is *A S* to *A V*, and so is *C S* to *C V*.—N. B. In all angles less than a minute of a degree, the sines, tangents, and arcs, are so nearly equal, that they may without error be used for one another. And here we make use of Gardiner's logarithmic tables, because they have the sines to every second of a degree.

ber of miles contained in the Earth's semidiameter, will give the number of miles by which the Sun is distant from the Earth's centre.

Then, by § 429, as 100000, the Earth's mean distance from the Sun in parts, is to 38710, Mercury's mean distance from the Sun in parts, so is the Earth's mean distance from the Sun in miles to Mercury's mean distance from the Sun in miles.—And,

As 100000 is to 72333, so is the Earth's mean distance from the Sun in miles to Venus's mean distance from the Sun in miles.—Likewise,

As 100000 is to 152369, so is the Earth's mean distance from the Sun in miles to Mars's mean distance from the Sun in miles —Again,

As 100000 is to 520096, so is the Earth's mean distance from the Sun in miles to Jupiter's mean distance from the Sun in miles.—Lastly,

As 100000 is to 954006, so is the Earth's mean distance from the Sun in miles to Saturn's mean distance from the Sun in miles.

And thus, by having found the distance of any one of the planets from the Sun, we have sufficient *data* for finding the distances of all the rest. And then, from their apparent diameters at these known distances, their real diameters and bulks may be found.

423. The Earth's diameter, as seen from the Sun, subtends an angle of double the Sun's horizontal parallax, at the time of of the Earth's mean distance from the Sun; and the Sun's diameter, as seen from the Earth at that time, subtends an angle of 32′ 2″, or 1922″. Therefore, the Sun's diameter is to the Earth's diameter, as 1922 is to 21. And since the relative bulks of spherical bodies are as the cubes of their diameters, the Sun's bulk is to the Earth's bulk, as 756058 is to 1; supposing the Sun's mean horizontal parallax to be 10″.50, as above.

Plate XIV. Fig. 4. 424. It is plain by Fig. 4, that whether Venus be at *U* or *V*, or in any other part of the right line *B V S*, it will make no difference in the time of her total ingress on the Sun at *S*, as seen from *B*; but as seen from *A* it will. For, if Venus be at *V*, her horizontal parallax from the Sun is the arc *F e*, which measures the angle *F A e*: but if she be nearer the Earth, as at *U*, her horizontal parallax from the

Sun is the arc *f e*, which measures the angle *f A e*; and this angle is greater than the angle *F A e*, by the difference of their measures *f F*. So that, as the distance of the celestial object from the Earth is less, its parallax is the greater.

425. To find the parallax of Venus by the above method, it is necessary, 1, That the difference of meridians of the two places of observation be 90°; 2, That the time of Venus's total ingress on the Sun be when his eastern limb is either on the meridian of one of the places, or very near it; and, 3, That each observer has his clock exactly regulated to the equal time at his place. But as it might, perhaps, be difficult to find two places on the Earth suited to the first and second of these requisites, we shall show how this important problem may be solved by a single observer, if he be exact as to his longitude, and has his clock truly adjusted to the equal time at his place.

426. That part of Venus's orbit in which she will move during her transit over the Sun, may be considered as a straight line; and, therefore, a plane may be conceived to pass both through it and the Earth's centre. To every place on the Earth's surface cut by this plane, Venus will be seen on the Sun in the same path that she would describe as seen from the Earth's centre; and therefore she will have no parallax of latitude, either north or south; but will have a greater or less parallax of longitude, as she is more or less distant from the meridian, at any time during her transit.

Matura, a town and fort on the south coast of the island of Ceylon, will be in this plane at the time of Venus's total ingress on the Sun; and the Sun will then be 62½° east of the meridian of that place. Consequently, to an observer at Matura, Venus will have a considerable parallax of longitude eastward from the Sun, when she would appear to touch the Sun's eastern limb as seen from the Earth's centre, at which the astronomical tables suppose the observer to be placed, and give the times as seen from thence.

427. According to these tables, Venus's total ingress on the Sun will be 50 minutes after VII in the morning at Matura,[3] supposing that place to be 80° east longitude from the meridian

[3] The time of total ingress at London, as seen from the Earth's centre, is at 30 minutes after II in the morning; and if Matura be just 80° (or 5 hours 20 minutes) east of London, when it is 30 minutes past II in the morning at London, it is 50 minutes past VII at Matura.

of London; which is the observer's business to determine. Let us imagine that he finds it to be exactly so, but that to him the total ingress is at VII hours 55 minutes 46 seconds, which is 5 minutes 46 seconds later than the true calculated time of total ingress, as seen from the Earth's centre. Then, as Venus's motion on (or towards, or from) the Sun is at the rate of 4 minutes of a degree in an hour (by § 418), her motion must be 23″.1 of a degree in 5 minutes 46 seconds of time; and this 23″.1 is her parallax eastward, from her total ingress as seen from Matura, when her ingress would be total if seen from the Earth's centre.

428. At VII hours 50 minutes in the morning, the Sun is $62\frac{1}{2}°$ from the meridian; at VI in the morning he is 90° from it: therefore, as the sine of $62\frac{1}{2}°$ is to the sine of 23″.1 (which is Venus's parallax from her true place on the Sun at VII hours 50 minutes) so is radius, or the sine of 90°, to the sine of 26″, which is Venus's horizontal parallax from the Sun at VI. In logarithms thus:—

As the logarithmic sine of 62° 30′	9.9479289
Is to the logarithmic sine of 23″.1	6.0481510
So is the logarithmic radius	10.0000000
To the logarithmic sine of 26″ very nearly	6.1002221

Divide the Sun's distance from the Earth, 1015, by his distance from Venus 726 (§ 12), and the quotient will be 1.3980; which being multiplied by Venus's horizontal parallax from the Sun 26″, will give 36″.3480, for her horizontal parallax as seen from the Earth at that time. Then (by § 421) as the Sun's distance 1015 is to Venus's distance 289, so is Venus's horizontal parallax 36″.3480 to the Sun's horizontal parallax 10″.3498. If Venus's horizontal parallax from the Sun is found by observation to be greater or less than 26″, the Sun's horizontal parallax must be greater or less than 10″.3498 accordingly.

429. And thus, by a single observation, the parallax of Venus, and consequently the parallax of the Sun, might be found, if we were sure that the astronomical tables were quite correct as to the time of Venus's total ingress on the Sun. But although the tables may be safely depended upon for shewing the true duration of the transit, which will not be quite 6 hours from the time of Venus's total ingress on the

Sun's eastern limb, to the beginning of her egress from his western; yet they may perhaps not give the true times of these two internal contacts: like a good common clock, which though it may be trusted to for measuring a few hours of itme, yet perhaps it may not be quite adjusted to the meridian of the place, and consequently not true as to any one hour; which every one knows is generally the case. Therefore, to make sure work, the observer ought to watch both the moment of Venus's total ingress on the Sun, and her beginning of egress from him, so as to note precisely the times between these two instants, by means of a good clock: and by comparing the interval at his place with the true calculated interval as seen from the Earth's centre, which will be 5 hours 58 minutes, he may find the parallax of Venus from the Sun both at her total ingress and beginning of egress.

430 The manner of observing the transit should be as follows—The observer being provided with a good telescope, and a pendulum clock well adjusted to the mean diurnal revolution of the Sun, and as near to the time at his place as conveniently may be; and having an assistant to watch the clock at the proper times, he must begin to observe the Sun's eastern limb through his telescope, twenty minutes at least before the computed time of Venus's total ingress upon it, lest there should be an error in the time thereof, as given by the tables. Method of observing the transit.

When he perceives a dent (as it were) to be made in the Sun's limb by the interposition of the dark body of Venus, he must then continue to watch her through the telescope as the dent increases; and his assistant must watch the time shewn by the clock, till the whole body of the planet appears just within the Sun's limb: and the moment when the bright limb of the Sun appears close by the east side of the dark limb of the planet, the observer, having a little hammer in his hand, is to strike a blow therewith on the table or wall, the moment of which, the assistant notes by the clock, and writes it down.

Then, let the planet pass on for about 2 hours 59 minutes, in which time it will be got to the middle of its apparent path on the Sun, and consequently will then be at its least apparent distance from the Sun's centre; at which time, the observer must take its distance from the Sun's centre, by means of a good micrometer, in order to ascertain its true latitude or de-

clination from the ecliptic, and thereby find the places of its nodes.

This done, there is but little occasion to observe it any longer, until it comes so near the Sun's western limb, as almost to touch it. Then the observer must watch the planet carefully with his telescope; and his assistant must watch the clock, so as to note the precise moment of the planet's touching the Sun's limb, which the assistant knows by the observer striking a blow with his hammer.

431. The assistant must be very careful in observing what minute on the dial-plate the minute-hand has past, when he has observed the second hand at the instant the blow was struck by the hammer; otherwise, though he be right as to the number of seconds of the current minute, he may be apt to make a mistake in the number of minutes.

432. To those places where the transit begins before XII at noon, and ends after it, Venus will have an eastern parallax from the Sun at the beginning, and a western parallax from the Sun at the end: which will contract the duration of the transit, by causing it to begin later, and end sooner at these places, than it does as seen from the Earth's centre; which may be explained in the following manner —

Fig. 5. In Fig 5, of Plate XIV, let *B M A* be the Earth, *V* Venus, and *S* the Sun The Earth's motion on its axis from west to east, or in the direction *A M B*, carries an observer on that side contrary to the motion of Venus in her orbit, which is in the direction *U V W*, and will therefore cause her motion to appear quicker on the Sun's disc, than it would appear to an observer placed at the Earth's centre *C*, or at either of its poles. For, if Venus were to stand still in her orbit at *V*, for twelve hours, the observer on the Earth's surface would, in that time, be carried from *A* to *B*, through the arc *A M B*. When he was at *A*, he would see Venus on the Sun at *R*; when at *M*, he would see her at *S*, and when he was at *B*, he would see her at *T*: so that his own motion would cause the planet to appear in motion on the Sun through the line *R S T*: which being in the direction of her apparent motion on the Sun as she moves in her orbit *U W*, her motion will be accelerated on the Sun to this observer, just as much as his own motion would shift her apparent place on the Sun, if she were at rest in her orbit at *V*.

But as the whole duration of the transit, from first to last internal contact, will not be quite six hours; an observer, who has the Sun on his meridian at the middle of the transit will be carried only from *a* to *b* during the whole time thereof. And therefore, the duration will be much less contracted by his own motion, than if the planet were to be twelve hours in passing over the Sun, as seen from the Earth's centre.

433. The nearer Venus is to the Earth, the greater is her parallax, and the more will the true duration of her transit be contracted thereby; the farther she is from the Earth, the contrary; so that the contraction will be in direct proportion to the parallax. Therefore, by observing, at proper places, how much the duration of the transit is less than its true duration at the Earth's centre, where it is 5 hours 58 minutes, as given by the astronomical tables, the parallax of Venus will be ascertained.

434. The above method (§ 17, *& seq.*) is much the same as was prescribed long ago by Doctor Halley, but the calculations differ considerably from his; as will appear in the next article, which contains a translation of the doctor's whole dissertation on that subject. He had not computed his own tables when he wrote it, nor had he time before-hand to make a sufficient number of observations on the motion of Venus, so as to determine whether the nodes of her orbit are at rest or no; and was therefore obliged to trust to other tables, which are now found to be erroneous.

ART. III.—*Containing Dr. Halley's Dissertation on the method of finding the Sun's parallax and distance from the Earth, by the transit of Venus over the Sun's disc, June 6, 1761. Translated from the Latin in Motte's Abridgment of the Philosophical Transactions, Vol. I, p. 243; with additional notes.*

435. There are many things exceedingly paradoxical, and that seem quite incredible to the illiterate, which yet by means of mathematical principles may be easily solved. Scarce any problem will appear more hard and difficult, than that of determining the distance of the Sun from the Earth very near the truth; Apparent difficulty of determining the Sun's distance.

but even this, when we are made acquainted with some exact observations, taken at places fixed upon, and chosen beforehand, will without much labour be effected. And this is what I am now desirous to lay before the Royal Society (which I foretel will continue for ages), that I may explain before-hand to young astronomers, who may perhaps live to observe these things, the method whereby the immense distance of the Sun may be truly obtained, to within a five-hundredth part of what it really is.

Various opinions among astronomers about the distance of the Sun.

436. It is well known that the distance of the Sun from the Earth is by different astronomers supposed different, according to what was judged most probable from the best conjecture that each could form. Ptolemy and his followers, as also Copernicus and Tycho Brahe thought it to be 1200 semidiameters of the Earth; Kepler 3500 nearly, Ricciolus doubles the distance mentioned by Kepler, and Hevelius only increases it by one-half. But the planets Venus and Mercury having, by the assistance of the telescope, been seen on the disc of the Sun, deprived of their borrowed brightness, it is at length found that the apparent diameters of the planets are much less than they were formerly supposed; and that the semidiameter of Venus seen from the Sun subtends no more than a fourth part of minute, or fifteen seconds, whilst the semidiameter of Mercury, at its mean distance from the Sun, is seen under an angle only of ten seconds; that the semidiameter of Saturn seen from the Sun, appears under the same angle; and that the semidiameter of Jupiter, the largest of all the planets, subtends an angle of no more than a third part of a minute at the Sun. Whence, keeping the proportion, some modern astronomers have thought, that the semidiameter of the Earth, seen from the Sun, would subtend a mean angle between that larger one subtended by Jupiter, and that smaller one subtended by Saturn and Mercury; and equal to that subtended by Venus (namely, fifteen seconds): and have thence concluded, that the Sun is distant from the Earth almost 14,000 of the Earth's semidiameters. But the same authors have, on another account, somewhat increased this distance: for, inasmuch as the Moon's diameter is a little more than a fourth part of the diameter of the Earth, if the Sun's parallax should be supposed fifteen seconds, it would follow, that the body of the Moon is larger than that of

Mercury; that is, that a secondary planet would be greater than a primary, which would seem inconsistent with the uniformity of the mundane system. And, on the contrary, the same regularity and uniformity seems scarcely to admit, that Venus, an inferior planet, that has no satellite, should be greater than our Earth, which stands higher in the system, and has such a splendid attendant. Therefore, to observe a mean, let us suppose the semidiameter of the Earth seen from the Sun, or, which is the same thing, the Sun's horizontal parallax, to be twelve seconds and a half; according to which, the Moon will be less than Mercury, and the Earth larger than Venus; and the Sun's distance from the Earth will come out nearly 16,500 of the Earth's semidiameters. This distance I assent to at present, as the true one, till it shall become certain what it is, by the experiment which I propose. Nor am I induced to alter my opinion by the authority of those (however weighty it may be) who are for placing the Sun at an immense distance beyond the bounds here assigned, relying on observations made upon the vibrations of a pendulum, in order to determine those exceeding small angles; but which, as it seems, are not sufficient to be depended upon: at least, by this method of investigating the parallax, it will come out sometimes nothing, or even negative; that is, the distance would either become infinite, or greater than infinite; which is absurd. And indeed, to confess the truth, it is hardly possible for a man to distinguish, with any degree of certainty, seconds, or even ten seconds, with instruments, let them be ever so skilfully made: therefore, it is not at all to be wondered at, that the excessive nicety of this matter has eluded the many and ingenious endeavours of such skilful operators.

When Dr. Halley was observing a transit of Mercury at St. Helena, he first thought of thence determining the Sun's distance.

487. "About forty years ago, whilst I was in the island of St. Helena, observing the stars about the south pole, I had an opportunity of observing, with the greatest diligence, Mercury passing over the disc of the Sun; and (which succeeded better than I could have hoped for) I observed, with the greatest degree of accuracy, by means of a telescope 24 feet long, the very moment when Mercury, entering upon the Sun, seemed to touch its limb within, and also the moment when going off, it struck the limb of the Sun's dic, forming the angle of interior contact: whence I found the interval of time, during which Mercury then appeared within the Sun's

disc, even without an error of one second of time. For the lucid line intercepted between the dark limb of the planet and the bright limb of the Sun, although exceedingly fine, is seen by the eye; and the little dent made in the Sun's limb, by Mercury's entering the disc, appears to vanish in a moment; and also that made by Mercury, when leaving the disc, seems to begin in an instant. When I perceived this, it immediately came into my mind, that the Sun's parallax might be accurately determined by such kind of observations as these;[4] provided Mercury were but nearer to the Earth, and had a greater parallax from the Sun: but the difference of these parallaxes is so little, as always to be less than the solar parallax which we seek; and therefore Mercury, though frequently to be seen on the Sun, is not to be looked upon as fit for our purpose."

The transits of Venus more suitable for determining the Sun's distance.

438. There remains then the transit of Venus over the Sun's disc, whose parallax, being almost four times as great as the solar parallax, will cause very sensible differences between the times in which Venus will seem to be passing over the Sun at different parts of the Earth. And from these differences, if they be observed as they ought, the Sun's parallax may be determined even to a small part of a second. Nor do we require any other instruments for this purpose than common telescopes and clocks, only good of their kind; and in the observers, nothing more is needful than fidelity, diligence, and a moderate skill in astronomy. For there is no need that the latitude of the place should be scrupulously observed, nor that the hours themselves should be accurately determined with respect to the meridian: it is sufficient that the clocks be regulated according to the motion of the heavens, if the times be well reckoned from the total ingress of Venus into the Sun's disc, to the beginning of her egress from it; that is, when the dark globe of Venus first begins to touch the bright limb of the Sun within; which moments, I know by my own experience, may be observed within a second of time.

Transits of Venus seldom happen.

439. But on account of the very strict laws by which the motions of the planets are regulated, Venus is seldom seen within the Sun's disc: and dur-

[4] Our celebrated countryman, James Gregory, first pointed out, in his *Optica Promota*, Schol. Prop. 87, published in 1663, the great use of the transits of Venus and Mercury in determining the Sun's parallax. See EDIN. ENCYCLOPAEDIA, Art. GREGORY, vol. x, p. 507.—*Ed.*

ing the course of more than 120 years, it could not be seen once; namely, from the year 1639 (when this most pleasing sight happened to that excellent youth Horrox our countryman, and to him only, since the creation) to the year 1761; in which year, according to the theories which we have hitherto found agreeable to the celestial motions, Venus will again pass over the Sun on the 26th of May (6th June new style), in the morning; so that at London, about six o'clock in the morning, we may expect to see it near the middle of the Sun's disc, and not above four minutes of a degree south of the Sun's centre. But the duration of this transit will be almost eight hours; namely, from two o'clock in the morning till almost ten. Hence the ingress will not be visible in England; but, as the Sun will at that time be in the 16th degree of Gemini, having almost 23 degrees north declination, it will be seen without setting at all in almost all parts of the north frigid zone: and therefore the inhabitants of the coast of Norway, beyond the city of Nidrosia, which is called Drontheim, as far as the North Cape, will be able to observe Venus entering the Sun's disc; and perhaps the ingress of Venus upon the Sun, when rising, will be seen by the Scotch, in the northern parts of the kingdom, and by the inhabitants of the Shetland isles, formerly called Thule. But at the time when Venus will be nearest the Sun's centre, the Sun will be vertical to the northern shores of the bay of Bengal or rather over the kingdom of Pegu; and therefore in the adjacent regions, as the Sun, when Venus enters his disc, will be almost four hours toward the east, and as many toward the west when she leaves him, the apparent motion of Venus on the Sun will be accelerated by almost double the horizontal parallax of Venus from the Sun; because Venus at that time is carried with a retrograde motion from east to west, whilst an eye placed upon the Earth's surface is whirled the contrary way, from west to east.[5]

[5] This has been already taken notice of in § 432; but I shall here endeavour to explain it more at large, together with some of the following part of the doctor's essay, by a figure.

In Fig. 4, of Plate XV, let *C* be the centre of the Earth, and *Z* the centre of the Sun. In the right line *C v Z*, make *v Z* to *C Z* as 726 is to 1015 (§ 420). Let *a c b d* be the Earth, *v* Venus's place in her orbit at the time of her conjunction with the Sun; and let *T S U* be the Sun, whose diameter is 31′ 42″.

The motion of Venus in her orbit is in the direction *N v n*, and the Earth's motion on its axis is, according to the order of the 24 hours placed around it in the figure. Therefore, supposing the mouth of the Ganges to be at *G*, when Venus is

440. Supposing the Sun's parallax (as we have said) to be $12\frac{1}{2}''$, the parallax of Venus will be 43″; from which sub-

at *E* in her orbit, and to be carried from *G* to *g* by the Earth's motion on its axis, whilst Venus moves from *E* to *e* in her orbit; it is plain, that the motions of Venus and the Ganges are contrary to each other.

The true motion of Venus in her orbit, and consequently the space she seems to run over on the Sun's disc in any given time, could be seen only from the Earth's centre *C*, which is at rest with respect to its surface. And as seen from *C*, her path on the Sun would be in the right line *T t U*; and her motion therein at the rate of four minutes of a degree in an hour. *T* is the point of the Sun's eastern limb, which Venus seems to touch at the moment of her total ingress on the Sun, as seen from *C*, when Venus is at *E* in her orbit; and *U* is the point of the Sun's western limb, which she seems to touch at the moment of her beginning of egress from the Sun, as seen from *C*, when she is at *e* in her orbit.

When the mouth of the Ganges is at *m* (in revolving through the arc *G m g*) the Sun is on its meridian. Therefore, since *G* and *g* are equally distant from *m* at the beginning and ending of the transit, it is plain that the Sun will be as far east of the meridian of the Ganges (at *G*), when the transit begins, as it will be west of the meridian of the same place (revolved from *G* to *g*) when the transit ends.

But although the beginning of the transit, or rather the moment of Venus's total ingress upon the Sun at *T*, as seen from the Earth's centre, must be when Venus is at *E* in her orbit, because she is then seen in the direction of the right line *C E T*; yet, at the same instant of time, as seen from the Ganges at *G*, she will be short of her ingress on the Sun, being then seen eastward of him, in the right line *G E K*, which makes the angle *K E T* (equal to the opposite angle *G E C*), with the right line *C E T*. This angle is called the angle of Venus's parallax from the Sun, which retards the beginning of the transit as seen from the banks of the Ganges; so that the Ganges *G* must advance a little farther towards *m*, and Venus must move on in her orbit from *E* to *R*, before she can be seen from *G* (in the right line *G R T*) wholly within the Sun's disc at *I*.

When Venus comes to *e* in her orbit, she will appear at *U*, as seen from the Earth's centre *C*, just beginning to leave the Sun; that is, at the beginning of her egress from his western limb: but, at the same instant of time, as seen from the Ganges, which is then at *g*, she will be quite clear of the Sun towards the west; being then seen from *g* in the right line *g e L*, which makes an angle, as *U e L* (equal to the opposite angle *C e g*) with the right line *C e U*; and this is the angle of Venus's parallax from the Sun, as seen from the Ganges at *g*, when she is but just beginning to leave the Sun at *U*, as seen from the Earth's centre *C*.

Here it is plain that the duration of the transit about the mouth of the Ganges (and also in the neighbouring places) will be diminished by about double the quantity of Venus's parallax from the Sun at the beginning and ending of the transit. For Venus must be at *E* in her orbit when she is wholly upon the Sun at *T*, as seen from the Earth's centre *C*; but at that time she is short of the Sun as seen from the Ganges at *G*, by the whole quantity of her eastern parallax from the Sun at that time, which is the angle *K E T*. [This angle, in fact, is only 23″, though it is represented much larger in the figure, because the Earth therein is a vast deal too big.] Now, as Venus moves at the rate of 4′ in an hour, she will move 23″ in 5 minutes 45 seconds: and therefore the transit will be 5 minutes 45 seconds later of beginning at the banks of the Ganges than at the Earth's centre. When the transit is ending at *U*, as seen from the Earth's centre at *C*, Venus will be

tracting the parallax of the Sun, there will remain 30″ at least for the horizontal parallax of Venus from the Sun; and therefore the motion of Venus will be increased 45″ at least by that parallax, whilst she passes over the Sun's disc, in those elevations of the pole which are in places near the tropic, and yet more in the neighbourhood of the equator. Now, Venus at that time will move on the Sun's disc, very nearly at the rate of four minutes of a degree in an hour; and therefore eleven minutes of time at least are to be allowed for 45″, or three-fourths of a minute of a degree; and by this space of time the duration of this eclipse caused by Venus will, on account of the parallax, be shortened; and from this shortening of the time only, we might safely enough draw a conclusion concerning the parallax which we are in search of, provided the diameter of the Sun and the latitude of Venus were accurately known. But we cannot expect an exact computation in a matter of such subtility.

141. We must endeavour therefore to obtain, if possible, another observation, to be taken in those places where Venus will be in the middle of the Sun's disc at midnight; that is, in places under the opposite meridian to the former, or about six hours or ninety degrees west of London; and where Venus enters upon the Sun a little before its setting, and goes off a little after its rising. And this will happen under the above-mentioned meridian, and where the elevation of the north pole is about 56 degrees; that is, in a part of Hudson's Bay, near a place called Port-Nelson. For, in this and the adjacent places, the parallax of Venus will increase the duration of the transit by at least six minutes of time; because, whilst the Sun, from its setting to its rising, seems to pass under the pole, those places on the Earth's disc will be carried with a motion from east to west, contrary to the motion of the Ganges; that is, with a motion conspiring with the motion of Venus;

quite clear of the Sun (by the whole quantity of her western parallax from him), as seen from the Ganges, which is then at *g*; and this parallax will be 22″, equal to the space through which Venus moves in 5 minutes 30 seconds of time; so that the transit will end 5½ minutes sooner as seen from the Ganges, than as seen from the Earth's centre.

Hence the whole contraction of the duration of the transit at the mouth of the Ganges will be 11 minutes 15 seconds of time; for it is 5 minutes 45 seconds at the beginning, and 5 minutes 30 seconds at the end.

and therefore Venus will seem to move more slowly on the Sun, and to be longer in passing over his disc.*

442. If, therefore, it should happen that this transit should be properly observed by skilful persons at both these places, it is clear that the duration thereof will be 17 minutes longer, as seen from Port-Nelson, than as seen from the East Indies. Nor is it of much consequence (if the English shall at that time give any attention to this affair), whether the observation be made at Fort-George, commonly called Madras, or at Bencoolen, on the western shore of the island of Sumatra, near the equator. But if the French should be disposed to take any pains herein, an observer may station himself conveniently enough at Pondicherry, on the west shore of the bay of Bengal, where the altitude of the pole is about twelve degrees. As to the Dutch, their celebrated mart at Batavia will afford them a place of observation fit enough for this purpose, provided they also have but a disposition to assist in advancing, in this par-

* In Fig. 1. of Plate XV, let *a C* be the meridian of the eastern mouth of the Ganges, and *b C* the meridian of Port-Nelson, at the mouth of York River in Hudson's Bay, 56° north latitude. As the meridian of the Ganges revolves from *a* to *c*, the meridian of Port-Nelson will revolve from *b* to *d*; therefore, whilst the Ganges revolves from *G* to *g*, through the arc *G m g*, Port-Nelson revolves the contrary way (as seen from the Sun or Venus) from *P* to *p*, through the arc *P n p*. Now, as the motion of Venus is from *E* to *e* in her orbit, while she seems to pass over the Sun's disc in the right line *T t U*, as seen from the Earth's centre *C*, it is plain that, whilst the motion of the Ganges is contrary to the motion of Venus in her orbit, and thereby shortens the duration of the transit at that place, the motion of Port-Nelson is the same way as the motion of Venus, and will therefore increase the duration of the transit; which may in some degree be illustrated by supposing that, whilst a ship is under sail, if two birds fly along the side of the ship in contrary directions to each other, the bird which flies contrary to the motion of the ship will pass by it sooner than the bird will which flies the same way that the ship moves.

In fine, it is plain by the figure, that the duration of the transit must be longer as seen from Port-Nelson, than as seen from the Earth's centre; and longer as seen from the Earth's centre, than as seen from the mouth of the Ganges. For Port-Nelson must be at *P*, and Venus at *N* in her orbit, when she appears wholly within the Sun at *T*; and the same place must be at *p*, and Venus at *n*, when she appears at *U*, beginning to leave the Sun. The Ganges must be at *G*, and Venus at *R*, when she is seen from *G* upon the Sun at *T*; and the same place must be at *g*, and Venus at *r*, when she begins to leave the Sun at *U*, as seen from *g*. So that Venus must move from *N* to *n* in her orbit, whilst she is seen to pass over the Sun from Port-Nelson; from *E* to *e* in passing over the Sun, as seen from the Earth's centre; and only from *R* to *r* whilst she passes over the Sun, as seen from the banks of the Ganges.

ticular, the knowledge of the heavens. And indeed I could wish that many observations of the same phenomenon might be taken by different persons at several places, both that we might arrive at a greater degree of certainty by their agreement, and also lest any single observer should be deprived, by the intervention of clouds, of a sight, which I know not whether any man living in this or the next age will ever see again; and on which depends the certain and adequate solution of a problem the most noble, and at any other time not to be attained to. I recommend it therefore again and again to those curious astronomers, who (when I am dead) will have an opportunity of observing these things, that they would remember this my admonition, and diligently apply themselves with all their might to the making this observation; and I earnestly wish them all imaginable success; in the first place, that they may not, by the unseasonable obscurity of a cloudy sky, be deprived of this most desirable sight; and then, that having ascertained with more exactness the magnitudes of the planetary orbits, it may redound to their immortal fame and glory.

443. We have now shewn, that by this method the Sun's parallax may be investigated to within its five hundredth part, which doubtless will appear wonderful to some. But if an accurate observation be made in each of the places above marked out, we have already demonstrated that the durations of this eclipse made by Venus, will differ from each other by 17 minutes of time; that is, upon a supposition that the Sun's parallax is $12\frac{1}{2}''$. But if the difference shall be found by observation to be greater or less, the Sun's parallax will be greater or less, nearly in the same proportion. And since 17 minutes of time are answerable to $12\frac{1}{2}$ seconds of solar parallax, for every second of parallax there will arise a difference of more than 80 seconds of time; whence, if we have this difference true to two seconds, it will be certain what the Sun's parallax is, to within a 40th part of one second; and therefore his distance will be determined to within its 500th part at least, if the parallax be not found less than what we have supposed; for 40 times $12\frac{1}{2}$ make 500.

444. And now I think I have explained this matter fully, and even more than I needed to have done, to those who understand astronomy: and I would have them take notice, that on this occasion I have had no regard to the latitude of Venus, both to avoid the inconvenience of a more intricate calculation,

which would render the conclusion less evident; and also because the motion of the nodes of Venus is not yet discovered, nor can be determined but by such conjunctions of the planet with the Sun as this is. For we conclude that Venus will pass four minutes below the Sun's centre, only in consequence of the supposition that the plane of Venus's orbit is immoveable in the sphere of the fixed stars, and that its nodes remain in the same places where they were found in the year 1639. But if Venus, in the year 1671, should move over the Sun in a path more to the south, it will be manifest that her nodes have moved backward among the fixed stars; and if more to the north, that they have moved forward; and that at the rate of $5\frac{1}{2}$ minutes of a degree in 100 Julian years for every minute that Venus's path shall be more or less distant than the abovesaid four minutes from the Sun's centre. And the difference between the durations of these eclipses will be somewhat less than 17 minutes of time, on account of Venus's south latitude, but greater, if, by the motion of the nodes forward, she should pass on the north of the Sun's centre.

But, for the sake of those who, though they are delighted with sydereal observations, may not have yet made themselves acquainted with the doctrine of parallaxes, I choose to explain the thing a little more fully by a scheme, and also by a calculation somewhat more accurate.

445. Let us suppose that at London, in the year 1761, on the 6th of June, at 55 minutes after V in the morning, the Sun will be in Gemini 15° 37′, and therefore that at its centre the ecliptic is inclined towards the north, in an angle of 6° 10′: and that the visible path of Venus on the Sun's disc at that time declines to the south, making an angle with the ecliptic of 8° 28′: then the path of Venus will also be inclined to the south with respect to the equator, intersecting the parallels of declination at an angle of 2° 18′[7]. Let us also suppose

[7] This was an oversight in the doctor, occasioned by his placing both the Earth's axis *B C g* (Fig. 2 of Plate XV), and the axis of Venus's orbit *C H*, on the same side of the axis of the ecliptic *C K*; the former making an angle of 6° 10′ therewith, and the latter an angle of 8° 28′; the difference of which angles is only 2° 18′. But the truth is, that the Earth's axis and the axis of Venus's orbit will then lie on different sides of the axis of the ecliptic, the former making an angle of 6° therewith, and the latter an angle of $8\frac{1}{2}$°. Therefore the sum of these angles, which is $14\frac{1}{2}$° (and not their difference, 2° 18′), is the inclination of Venus's visible path to the equator, and parallels of declination.

that Venus, at the forementioned time, will be at her least distance from the Sun's centre, viz. only four minutes to the south; and that every hour she will describe a space of four minutes on the Sun, with a retrograde motion. The Sun's semidiameter will be 15′ 51″ nearly, and that of Venus 37½″. And let us suppose, for trial's sake, that the difference of the horizontal parallaxes of Venus with the Sun (which we want) is 31″, such as it comes out if the Sun's parallax be supposed 12½″. Then, on the centre *C* (Plate XV, Fig. 2), let the little circle *A B*, representing the Earth's disc, be described, and let its semidiameter *C B* be 31″; and let the elliptic parallels of 22 and 56 degrees of north latitude (for the Ganges and Port-Nelson) be drawn within it, in the manner now used by astronomers for constructing solar eclipses. Let *B C g* be the meridian in which the Sun is, and to this let the right line *F H G*, representing the path of Venus, be inclined at an angle of 2° 18′; and let it be distant from the centre *C* 240 such parts, whereof *C B* is 31. From *C* let fall the right line *C H*, perpendicular to *F G*; and suppose Venus to be at *H* at 55 minutes after V in the morning. Let the right line *F H G* be divided into the horary spaces III IV, IV V, V VI, &c. each equal to *C H*; that is, to four minutes of a degree. Also, let the right line *L M* be equal to the difference of the apparent semidiameters of the Sun and Venus, which is 15′ 13½″; and a circle being described with the radius *L M*, on a centre taken in any point within the little circle *A B*, representing the Earth's disc, will meet the right line *F G* in a point denoting the time at London when Venus shall touch the Sun's limb internally, as seen from the place of the Earth's surface that answers to the point assumed in the Earth's disc. And if a circle be described on the centre *C*, with the radius *L M*, it will meet the right line *F G* in the points *F* and *G*; and the spaces *F H* and *G H* will be each equal to 14′ 4″, which space Venus will appear to pass over in three hours 40 minutes of time at London; therefore *F* will fall on two hours 15 minutes, and *G* in nine hours 35 minutes in the morning. Whence it is manifest, that if the magnitude of the Earth, on account of its immense distance, should vanish as it were into a point; or if, being deprived of a diurnal motion, it should always have the Sun vertical to the same point *C*, the whole duration of this eclipse would be seven hours

Plate XV, Fig. 2.

20 minutes. But the Earth in that time being whirled through 110 degrees of longitude, with a motion contrary to the motion of Venus, and consequently the above-mentioned duration being contracted, suppose 12 minutes, it will come out seven hours eight minutes, or 107 degrees, nearly.

446. Now, Venus will be at *H*, at her least distance from the Sun's centre, when in the meridian of the eastern mouth of the Ganges, where the altitude of the pole is about 22 degrees. The Sun therefore will be equally distant from the meridian of that place at the moments of the ingress and egress of the planet, viz. 53½ degrees; as the points *a* and *b* (representing that place in the Earth's disc *A B*) are, in the greater parallel, from the meridian *B C g*. But the diameter *c f* of that parallel will be to the distance *a b* as the square of the radius to the rectangle under the sines of 53½ and 68 degrees, that is, as 1′ 2″ to 46″ 13‴. And by a good calculation (which, that I may not tire the reader, it is better to omit), I find that a circle described on *a* as a centre, with the radius *L M*, will meet the right line *F H* in the point *M*, at two hours 20 minutes 40 seconds; but that being described round *b* as a centre, it will meet *H G* in the point *N* at nine hours 29 minutes 22 seconds, according to the time reckoned at London, and therefore Venus will be seen entirely within the Sun at banks of the Ganges for 7 hours 8 minutes 42 seconds: we have then rightly supposed that the duration will be 7 hours 8 minutes, since the part of a minute here is of no consequence.

But adapting the calculation to Port-Nelson, I find that the Sun being about to set, Venus will enter his disc; and immediately after his rising, she will leave the same. That place is carried in the intermediate time through the hemisphere opposite to the Sun, from *c* to *d*, with a motion conspiring with the motion of Venus; and therefore the stay of Venus on the Sun will be about 4 minutes longer, on account of the parallax; so that it will be at least 7 hours 24 minutes, or 111 degrees of the equator. And since the latitude of the place is 56 degrees, as the square of the radius is to the rectangle contained under the signs of 55½ and 34 degrees, so is *A B*, which is 1′ 2″, to *c d*, which is 28″ 38‴. And if the calculation be justly made, it will appear that a circle described on *c* as a centre, with the radius *L M*, will meet the right line *F H* in *O*, at 2 hours 12 minutes 45 se-

conds; and that such a circle, described on d as a centre, will meet $H G$ in P, at 9 hours 36 minutes 37 seconds; and therefore the duration at Port-Nelson will be 7 hours 23 minutes 52 seconds, which is greater than at the mouth of the Ganges by 15 minutes 10 seconds of time. But if Venus should pass over the Sun without having any latitude, the difference would be 18 minutes 40 seconds; and if she should pass 4′ north of the Sun's centre, the difference would amount to 21 minutes 40 seconds, and will be still greater, if the planet's north latitude be more increased.

117. From the foregoing hypothesis it follows, that at London, when the Sun rises, Venus will have entered his disc; and that, at 9 hours 37 minutes in the morning, she will touch the limb of the Sun internally in going off; and, lastly, that she will not entirely leave the Sun till 9 hours 56 minutes.

118. It likewise follows, from the same hypothesis, that the centre of Venus should just touch the Sun's northern limb in the year 1769, on the 3d of June, at 11 o'clock at night; so that, on account of the parallax, it will appear in the northern parts of Norway, entirely within the Sun, which then does not set to those parts; whilst, on the coasts of Peru and Chili, it will seem to travel over a small portion of the disc of the setting Sun; and over that of the rising Sun at the Molucca islands, and in their neighbourhood. But if the nodes of Venus be found to have a retrograde motion (as there is some reason to believe, from some later observations, they have), then Venus will be seen everywhere within the Sun's disc, and, will afford a much better method for finding the Sun's parallax, by almost the greatest difference in the duration of these eclipses that can possibly happen.

But how this parallax may be deduced from observations made somewhere in the East Indies, in the year 1761, both of the ingress and egress of Venus, and compared with those made in its going off with us; namely, by applying the angles of a triangle given in specie to the circumference of three equal circles, shall be explained on some other occasion.

ART. IV.—*Showing that the whole Method proposed by Dr. Halley cannot be put in practice.*

Remarks on Dr. Halley's Dissertation.

449. IN the above dissertation, the doctor has explained his method with great modesty, and even with some doubtfulness with regard to its full success. For he tells us that the Sun's parallax may only be determined within its five hundredth part thereby, provided it be not less than $12\frac{1}{2}''$; that there may be a good observation made at Port-Nelson, as well as about the banks of the Ganges; and that Venus does not pass more than four minutes of a degree below the centre of the Sun's disc. He has taken all proper pains not to raise our expectations too high, and yet, from his well known abilities and character as a great astronomer, it seems mankind in general have laid greater stress upon his method than he ever desired them to do. Only, as he was convinced it was the best method by which this important problem can ever be solved, he recommended it warmly for that reason. He had not then made a sufficient number of observations, whereby to determine with certainty whether the nodes of Venus's orbit have any motion at all; or, if they have, whether it be backward or forward with respect to the stars, and consequently, having not then made his own tables, he was obliged to calculate from the best that he could find. But those tables allow of no motion to Venus's nodes, and also reckon her conjunction with the Sun to be about half an hour too late.

450. But more modern observations prove that the nodes of Venus's orbit have a motion backward, or contrary to the order of the signs, with respect to the fixed stars. And this motion is allowed for in the doctor's tables, a great part whereof were made from his own observations. And it appears by these tables that Venus will be so much farther past her descending node at the time of this transit, than she was past her ascending node at her transit in November 1639, that instead of passing only four minutes of a degree below the Sun's centre in this, she will pass almost 10 minutes of a degree below it: on which account the line of her transit will be so much shortened, as will make her passage over the Sun's disc about an

hour and 20 minutes less than if she passed only 4 minutes below the Sun's centre, at the middle of her transit. And therefore her parallax from the Sun will be so much diminished, both at the beginning and end of her transit, and at all places from which the whole of it will be seen, that the difference of its durations, as seen from them, and as supposed to be seen from the Earth's centre, will not amount to 11 minutes of time.

451. But this is not all: for although the transit will begin before the Sun sets to Port-Nelson, it will be quite over before he rises to that place next morning, on account of its ending so much sooner than as given by the tables to which the doctor was obliged to trust; so that we are quite deprived of the advantage that otherwise would have arisen from observations made at Port-Nelson.

452. In order to trace this affair through all its intricacies, and to render it as intelligible to the reader as I can, there will be an unavoidable necessity of dwelling much longer upon it than I could otherwise wish. And as it is impossible to lay down truly the parallels of latitude, and the situations of places at particular times, in such a small disc of the Earth as must be projected in such a sort of diagram as the doctor has given, so as to measure thereby the exact times of the beginning and ending of the transit at any given place, unless the Sun's disc be made at least 30 inches diameter in the projection; and to which the doctor did not quite trust, without making some calculations; I shall take a different method, in which the Earth's disc may be made as large as the operator pleases; but if he makes it only six inches in diameter, he may measure the quantity of Venus's parallax from the Sun upon it, both in longitude and latitude, to the fourth part of a second, for any given time and place; and then, by an easy calculation in the common rule of three, he may find the effect of the parallaxes on the duration of the transit. In this, I shall first suppose with the doctor, that the Sun's horizontal parallax is $12\frac{1}{2}''$; and consequently that Venus's horizontal parallax from the Sun is 31″. And after projecting the transit, so as to find the total effect of the parallax upon its duration, I shall next shew how nearly the Sun's real parallax may be found from the observed intervals between the times of Venus's egress from the Sun, at particular places of the Earth; which is the method now taken

both by the English and French astronomers, and is a surer way whereby to come at the real quantity of the Sun's parallax, than by observing how much the whole contraction of duration of the transit is, either at Bencoolen, Batavia, or Pondicherry.

Art. V.—*Shewing how to project the Transit of Venus on the Sun's Disc, as seen from different Places of the Earth, so as to find what its visible Duration must be at any given Place, according to any assumed Parallax of the Sun, and from the observed Intervals between the Times of Venus's Egress from the Sun at particular Places, to find the Sun's true horizontal Parallax.*

Elements of the transit of Venus.

453. The elements for this projection are as follow:—

I. The true time of conjunction of the Sun and Venus, which, as seen from the Earth's centre, and reckoned according to the equal time at London, is, on the 6th of June 1761, at 46 minutes 17 seconds after V in the morning, according to Dr. Halley's tables.

II. The geocentric latitude of Venus at that time 9′ 43″ south

III. The Sun's semidiameter, 15′ 50″.

IV. The semidiameter of Venus (from the doctor's dissertation) 37½″.

V The difference of the semidiameters of the Sun and Venus, 15′ 12½″.

VI. Their sum, 16′ 27½″.

VII. The visible angle which the transit-line makes with the ecliptic, 8° 31′; the angular point (or descending node) being 1° 6′ 18″ eastward from the Sun, as seen from the Earth; the descending node being in ♐ 14 29′ 37″, as seen from the Sun; and the Sun in ♊ 15° 35′ 55″, as seen from the Earth.

VIII. The angle which the axis of Venus's visible path makes with the axis of the ecliptic, 8° 31′; the southern half of that axis being on the left hand (or eastward) of the axis of the ecliptic, as seen from the northern hemisphere of the Earth, which would be to the right hand, as seen from the Sun.

IX. The angle which the Earth's axis makes with the axis of the ecliptic, as seen from the Sun, 6°; the southern half of the Earth's axis lying to the right hand of the axis of the ecliptic, in the projection, which would be to the left hand as seen from the Sun.

X. The angle which the Earth's axis makes with the axis of Venus's visible path, 14° 31′, viz. the sum of Nos. VIII and IX.

XI. The true motion of Venus on the Sun, given by the tables as if it were seen from the Earth's centre, 4 minutes of a degree in 60 minutes of time.

454. These elements being collected, make a scale of any convenient length, as that of Fig. 1 in Plate XVI, and divide it into 17 equal parts, each whereof shall be taken for a minute of a degree; then divide the minute next to the left hand into 60 equal parts for seconds, by diagonal lines, as in the figure. The reason for dividing the scale into 17 parts or minutes is, because the sum of the semidiameters of the Sun and Venus exceeds 16 minutes of a degree.—See No. VI. Method of projecting Transits. Plate XVI, Fig. 1.

455. Draw the right line *A C G* (Fig. 2) for a small part of the ecliptic, and perpendicular thereto draw the right line *C v E* for the axis of the ecliptic on the southern half of the Sun's disc. Fig. 2.

456. Take the Sun's semidiameter, 15′ 50″, from the scale with your compasses; and, with that extent as a radius, set one foot in *C* as a centre, and describe the semicircle *A E G* for the southern half of the Sun's disc, because the transit is on that half of the Sun.

457. Take the geocentric latitude of Venus, 9′ 43″, from the scale with your compasses; and set the extent from *C* to *v*, on the axis of the ecliptic: and the point *v* shall be the place of Venus's centre on the Sun, at the tabular moment of her conjunction with the Sun.

458. Draw the right line *C B D*, making an angle of 8° 31′ with the axis of the ecliptic, towards the left hand, and this line shall represent the axis of Venus's geocentric visible path on the Sun.

459. Through the point of the conjunction *v*, in the axis of the ecliptic, draw the right line *q t r* for the geocentric visible path of Venus over the Sun's disc, at right angles to *C B D*,

the axis of her orbit, which axis will divide the line of her path into two equal parts *q t* and *t r*.

460. Take Venus's horary motion on the Sun, 4′, from the scale with your compasses; and with that extent make marks along the transit-line *q t r*. The equal spaces, from mark to mark, shew how much of that line Venus moves through in each hour, as seen from the Earth's centre, during her continuance on the Sun's disc.

461. Divide each of these horary spaces, from mark to mark, into 60 equal parts for minutes of time; and set the hours to the proper marks in such a manner that the true time of conjunction of the Sun and Venus, 46½ minutes after V in the morning, may fall into the point *v*, where the transit-line cuts the axis of the ecliptic. So the point *v* shall denote the place of Venus's centre on the Sun, at the instant of her ecliptical conjunction with the Sun, and *t* (in the axis *C t D* of her orbit) will be the middle of her transit, which is at 24 minutes after V in the morning, as seen from the Earth's centre, and reckoned by the equal time at London.

462. Take the difference of the semidiameters of the Sun and Venus, 15′ 12½″, in your compasses from the scale, and with that extent, setting one foot in the Sun's centre *C*, describe the arcs *N* and *T* with the other, crossing the transit-line in the points *k* and *l*; which are the points on the Sun's disc that are hid by the centre of Venus at the moments of her two internal contacts with the Sun's limb or edge, at *M* and *N*: the former of these is the moment of Venus's total ingress on the Sun, as seen from the Earth's centre, which is at 28 minutes after II in the morning, as reckoned at London; and the latter is the moment when her egress from the Sun begins, as seen from the Earth's centre, which is 20 minutes after VIII in the morning at London. The interval between these two contacts is 5 hours 52 minutes.

463. The central ingress of Venus on the Sun is the moment when her centre is on the Sun's eastern limb at *u*, which is at 15 minutes after II in the morning; and her central egress from the Sun is the moment when her centre is on the Sun's western limb at *w*, which is at 33 minutes after VIII in the morning, as seen from the Earth's centre, and reckoned according to the time at London. The interval between these times is 6 hours 18 minutes.

464. Take the sum of the semidiameters of the Sun and Venus, 16′ 27½″, in your compasses from the scale, and with that extent, setting one foot in the Sun's centre *C*, describe the arcs *Q* and *R* with the other, cutting the transit-line in the points *q* and *r*, which are the points in open space (clear of the Sun), where the centre of Venus is at the moments of her two external contacts with the Sun's limb at *S* and *W*; or the moments of the beginning and ending of the transit, as seen from the Earth's centre; the former of which is at 3 minutes after II in the morning at London, and the latter at 45 minutes after VIII. The interval between these moments is 6 hours 42 minutes.

465. Take the semidiameter of Venus, 37½″, in your compasses from the scale; and with that extent as a radius, on the points *q*, *k*, *t*, *l*, *r*, as centres, describe the circles *H S*, *M I*, *O F*, *P N*, *W Y*, for the disc of Venus, at her first contact at *S*, her total ingress at *M*, her place on the Sun at the middle of her transit, her beginning of egress at *N*, and her last contact at *W*.

466. Those who have a mind to project the Earth's disc on the Sun, round the centre *C*, and to lay down the parallels of latitude and situations of places thereon, according to Dr. Halley's method, may draw *C f* for the axis of the Earth, produced to the southern edge of the Sun at *f*; and making an angle *E C f* of 6° with the axis of the ecliptic *C E*: but he will find it very difficult and uncertain to mark the places on that disc, unless he makes the Sun's semidiameter *A C* 15 inches at least; otherwise the line *C f* is of no use at all in this projection. The following method is better:—

467. In Fig 3 of Plate XVI, make the line *A B* of any convenient length, and divide it into 31 equal parts, each whereof shall be taken for a second of Venus's parallax either from or upon the Sun (her horizontal parallax from the Sun being supposed to be 31″); and taking the whole length *A B* in your compasses, set one foot in *C* (Fig. 4) as a centre, and describe the circle *A E B D* for the Earth's enlightened disc, whose diameter is 62″, or double the horizontal parallax of Venus from the Sun. In this disc draw *A C B* for a small part of the ecliptic, and at right angles thereto draw *E C D* for the axis of the ecliptic. Draw also *N C S*, both for the Earth's axis

Plate XVI. Fig. 3.

Fig. 4.

and universal solar meridian, making an angle of 6° with the axis of the ecliptic, as seen from the Sun; *H C I* for the axis of Venus's orbit, making an angle of 8° 31′ with *E C D*, the axis of the ecliptic; and, lastly, *V C O* for a small part of Venus's orbit, at right angles to its axis.

468. This figure represents the Earth's enlightened disc, as seen from the Sun at the time of the transit. The parallels of latitude of London, the eastern mouth of the Ganges, Bencoolen, and the island of St. Helena, are laid down in it, in the same manner as they would appear to an observer on the Sun, if they were really drawn in circles on the Earth's surface (like those on a common terrestrial globe), and could be visible at such a distance. The method of delineating these parallels is the same as already described in the 19th chapter, for the construction of solar eclipses.

469. The points where the curved lines (called hour-circles) XI *N*, X *N*, &c. cut the parallels of latitude, or paths of the four places above mentioned, are the points at which the places themselves would appear in the disc, as seen from the Sun, at these hours respectively. When either place comes to the solar meridian *N C S* by the Earth's rotation on its axis, it is noon at that place; and the difference, in absolute time, between the noon at that place and the noon at any other place, is in proportion to the difference of longitude of these two places, reckoning one hour for every 15 degrees of longitude, and 4 minutes for each degree; adding the time if the longitude be east, but subtracting it if the longitude be west.

470. The distance of either of these places from *H C I*, the axis of Venus's orbit at any hour or part of an hour, being measured upon the scale *A B* in Fig. 3, will be equal to Venus's parallax in longitude, either on or from the Sun; and this parallax, being always contrary to the position of the place, is eastward as long as the place keeps on the left hand of the axis of the ecliptic, as seen from the Sun; and westward when the place gets to the right hand of the axis of the ecliptic. So that, to all the places which are posited in the hemisphere *H V I* of the disc, at any given time, Venus has an eastern parallax of longitude; but when the Earth's diurnal motion carries the same places into the hemisphere *H O I*, the parallax of Venus is westward.

471. When Venus has a parallax toward the east, as seen

from any given place on the Earth's surface, either at the time of her total ingress or beginning of egress, as seen from the Earth's centre; add the time answering to this parallax to the time of ingress or egress at the Earth's centre, and the sum will be the time thereof, as seen from the given place on the Earth's surface: but when the parallax is westward, subtract the time answering thereto from the time of total ingress or beginning of egress, as seen from the Earth's centre, and the remainder will be the time, as seen from the given place on the surface, so far as it is affected by this parallax. The reason of this is plain to every one who considers that an eastern parallax keeps the planet back, and a western parallax carries it forward, with respect to its true place or position at any instant of time, as seen from the Earth's centre.

472. The nearest distance of any given place from *V C O*, the plane of Venus's orbit at any hour or part of an hour, being measured on the scale *A B* in Fig. 3, will be equal to Venus's parallax in latitude, which is northward from the true line of her path on the Sun, as seen from the Earth's centre, if the given place be on the north side of the plane of her orbit *V C O* on the Earth's disc; and the contrary, if the given place be on the north side of that plane; that is, the parallax is always contrary to the situation of the place on the Earth's disc, with respect to the plane of Venus's orbit thereon.

473. As the line of Venus's transit is on the southern hemisphere of the Sun's disc, it is plain that a northern parallax in her latitude will cause her to describe a longer line on the Sun, than if she had no such parallax; and a southern parallax in latitude will cause her to describe a shorter line on the Sun, than if she had no such parallax. And the longer this line is, the sooner will her total ingress be, and the later will be her beginning of egress; and just the contrary, if the line be shorter. But, to all places situated on the north side of the plane of her orbit, in the hemisphere *V H O*, the parallax of latitude is south; and to all places situated on the south side of the plane of her orbit, in the hemisphere *V I O*, the parallax of latitude is north. Therefore, the line of the transit will be shorter to all places in the hemisphere *V H O*, than it will be as seen from the Earth's centre, where there is no parallax at all; and longer to all places in the hemisphere *V I O*. So that the time answering to this parallax must be added to the time of total in-

gress as seen from the Earth's centre, and subtracted from the beginning of egress as seen from the Earth's centre, in order to have the true time of total ingress and beginning of egress as seen from places in the hemisphere *V H O*: and just the reverse for places in the hemisphere *V I O*. It was proper to mention these circumstances, for the reader's more easily conceiving the reason of applying the times answering to the parallaxes of longitude and latitude in the subsequent part of this article: for it is their sum in some cases, and their difference in others, which being applied to the times of total ingress and beginning of egress as seen from the Earth's centre, that will give the times thereof as seen from the given places on the Earth's surface.

474. The angle which the Sun's semidiameter subtends, as seen from the Earth, at all times of the year, has been so well ascertained by late observations, that we can make no doubt of its being 15′ 50″ on the day of the transit; and Venus's latitude has also been so well ascertained at many different times of late, that we have very good reason to believe it will be 9′ 43″ south of the Sun's centre, at the time of her conjunction with the Sun. If, then, her semidiameter at that time be $37\frac{1}{2}$″ (as mentioned by Dr. Halley), it appears by the projection (Fig. 2), that her total ingress on the Sun as seen from the Earth's centre, will be at 28 minutes after II in the morning (§ 462), and her beginning of egress from the Sun will be 20 minutes after VIII, according to the time reckoned at London.

475. As the total ingress will not be visible at London, we shall not here trouble the reader about Venus's parallax at that time. But by projecting the situation of London on the Earth's disc (Fig. 4) for the time when the egress begins, we find it will then be at *l*, as seen from the Sun.

Fig. 4.

Draw *l d* parallel to Venus's orbit *V C O*, and *l u* perpendicular to it: the former is Venus's eastern parallax in longitude at her beginning of egress, and the latter is her southern parallax in latitude at that time. Take these in your compasses, and measure them on the scale *A B* (Fig. 3) and you will find the parallax in longitude to be $10\frac{3}{4}$″, and the parallax in latitude to be $21\frac{1}{2}$″.

Fig. 3.

476. As Venus's true motion on the Sun is at the rate of 4 minutes of a degree in 60 minutes of time, (see No. 11 of § 453), say, as 4 minutes of a degree is to 60 minutes of time, so is $10\frac{3}{4}$″

of a degree to 2 minutes 41 seconds of time; which being added to 8 hours 20 minutes (because this parallax is eastward, § 471), gives 8 hours 22 minutes 41 seconds, for the beginning of egress at London, as affected only by this parallax. But, as Venus has a southern parallax of latitude at that time, her beginning of egress will be sooner; for this parallax shortens the line of her visible transit at London.

As this parallax of latitude is $21\frac{1}{2}''$ south, add it to Venus's latitude $9' 43''$, and the sum will be $10' 4\frac{1}{2}''$; which is to be taken from the scale in Fig. 1, and set from *C* to *L* in Fig. 2. And then, if a line be drawn parallel to *t l*, it will terminate at the point *p* in the arc *T*, where Venus's centre will be at the beginning of her egress as seen from London.[7] But as her centre is at *l* when her egress begins as seen from the Earth's centre, take *L p* in your compasses, and setting that extent from *t* towards *l* on the central transit-line, you will find it to be 5 minutes shorter than *t l*: therefore subtract 5 minutes from 8 hours 22 minutes 41 seconds, and there will remain 8 hours 17 minutes 41 seconds for the visible beginning of egress in the morning at London.

477 At 5 hours 24 minutes (which is the middle of the transit as seen from the Earth's centre) London will be at *L* on the Earth's disc (Fig. 4) as seen from the Sun. The parallax of longitude *L a* is then $2\frac{1}{2}''$; by which, working as above directed, we find the middle of the transit, as seen from London, to be at 5 hours 20 minutes 53 seconds. This is not affected by the parallax of latitude *L t*. But *L t* measures $27''$ on the scale *A B* (Fig. 3); therefore take $27'$ from the scale in Fig. 1, and set it from *t* to *L*, on the axis of Venus's path in Fig. 2, and laying a ruler to the point *L*, and the above found point of egress *p*, draw *o L p* for the line of the transit as seen from London.

Fig. 4.

Fig. 3.

478. The eastern mouth of the river Ganges is 89 degrees east from the meridian of London; and therefore, when the time at London is 28 minutes after II in the morning (§ 462), it is 24 minutes past VIII in the morning (by § 469), at the mouth of the

[7] The reason why the lines *o L p*, *a B b*, *ct*, and *tb*, which are the visible transits at London, Bencoolen, the Ganges mouth, and St. Helena, are not parallel to the central transit-line *k t l*, is, because the parallaxes in latitude are different at the times of ingress and egress, as seen from each of these places. The method of drawing these lines will be shewn by and by.

Ganges; and when it is 20 minutes past VIII in the morning at London (§ 462), it is 16 minutes past II in the afternoon at the Ganges. Therefore, by projecting that place upon the Earth's disc, as seen from the Sun, it will be at *G* (in Fig. 4) at the time of Venus's total ingress, as seen from the Earth's centre, and at *g* when her egress begins.

Draw *G c* and *g r* parallel to the orbit of Venus *V C O*, and measure them on the scale *A B* in Fig. 3; the former will be 21″ for Venus's eastern parallax in longitude, at the above-mentioned time of her total ingress, and the latter will be 16½″ for her western parallax in longitude at the time when her egress begins. The former parallax gives 5 minutes 15 seconds of time (by the analogy in § 476) to be added to 8 hours 24 minutes, and the latter parallax gives 4 minutes 11 seconds to be subtracted from 2 hours 16 minutes; by which we have 8 hours 29 minutes 15 seconds, for the time of total ingress as seen from the banks of the Ganges, and 2 hours 11 minutes 49 seconds for the beginning of egress, as affected by these parallaxes.

Draw *Gf* perpendicular to Venus's orbit, *V O C*, and by measurement on the scale *A B* (Fig. 5), it will be found to contain 10; which being taken from the scale in Fig. 1, and set off southward from the point of total ingress *k* (Fig. 2, as seen from the Earth's centre) parallel to the axis of Venus's path, it will fall into the point *c* on the arc *N*. Draw *C t*, and taking the extent *t c* in your compasses, and applying it from *t* towards *k*, you will find it to fall a minute short of *k*; which shews, that Venus's parallax in latitude shortens the beginning of the line of her visible transit at the Ganges by one minute of time. Therefore, as this makes the visible ingress a minute later, add one minute to the above 8 hours 29 minutes 15 seconds, and it will give 8 hours 30 minutes 15 seconds for the time of total ingress in the morning, as seen from the eastern mouth of the Ganges. At the beginning of egress, the parallax of latitude *g p* is 2½″ (by measurement of the scale *A B*) which will protract the beginning of egress by about 30 seconds of time, and must therefore be added to the above 2 hours 11 minutes 49 seconds, which will make the visible beginning of egress to be at 2 hours 12 minutes 19 seconds in the afternoon.

479. Bencoolen is 102 degrees east from the meridian of London; and, therefore, when the time is 28 minutes past II

in the morning at London, it is 16 minutes past IX in the morning at Bencoolen; and when it is 20 minutes past VIII in the morning at London, it is 8 minutes past III in the afternoon at Bencoolen. Therefore, in Fig. 4, Bencoolen will be at *B* at the time of Venus's total ingress as seen from the Earth's centre, and at *b* when her egress begins

Draw *B i* and *b k* parallel to Venus's orbit *V C O*, and measure them on the scale: the former will be found to be 22″ for Venus's eastern parallax in longitude at the time of her total ingress, and the latter to be 19½″ for her western parallax in longitude when her egress begins, as seen from the Earth's centre. The first of these parallaxes gives 5 minutes 30 seconds (by the analogy in § 476) to be added to 9 hours 16 minutes, and the latter parallax gives 4 minutes 52 seconds to be subtracted from 3 hours 8 minutes; whence we have 9 hours 21 minutes 30 seconds for the time of total ingress at Bencoolen, and 3 hours and 8 minutes 3 seconds for the time when the egress begins there, as affected by these two parallaxes.

180. Draw *B r* and *b m* perpendicular to Venus's orbit *V C O*, and measure them on the scale *A B* in Fig. 3: the former will be 5″ for Venus's northern parallax in latitude as seen from Bencoolen at the time of her total ingress; and the latter will be 15½″ for her northern parallax in latitude when her egress begins. Take these parallaxes from the scale in Fig. 1, in your compasses, and set them off above the central transit-line perpendicular to the axis of Venus's path; the former from the left hand of *k* (Fig. 2), to *a* in the arc *N*, and the latter from the right hand of *l* to *b* in the arc *T*; and draw *a B b* for the line of Venus's transit as seen from Bencoolen: the centre of Venus being at *a*, as seen from Bencoolen, at the moment of her total ingress; and at *b* at the moment when her egress begins.

But as seen from the Earth's centre, the centre of Venus is at *k* in the former case, and at *l* in the latter: so that we find the line of the transit is longer as seen from Bencoolen than as seen from the Earth's centre, which is the effect of Venus's northern parallax in latitude. Take *B a* in your compasses, and setting that extent backward from *t* toward *g*, on the central transit-line, you will find it will reach two minutes beyond *k* thereon: and taking the extent *B b* in your compasses, and setting it forward from *t* towards *w*, on the central transit-line, it will be found to reach 3 minutes beyond *l* thereon. Consequently, if we subtract 2 minutes from 9 hours 21 minutes 30

seconds (above found), we have 9 hours 19 minutes 30 seconds in the morning, for the time of total ingress as seen from Bencoolen; and if we add 3 minutes to the above found 3 hours 3 minutes 8 seconds, we shall have 3 hours 6 minutes 8 seconds afternoon, for the time when the egress begins as seen from Bencoolen.

481. The whole duration of the transit, from total ingress to beginning of egress, as seen from the Earth's centre, is 5 hours 52 minutes (by § 462); but the whole duration from total ingress to beginning of egress, as seen from Bencoolen, is only 5 hours 46 minutes 38 seconds; which is 5 minutes 22 seconds less than as seen from the Earth's centre: and this 5 minutes 22 seconds is the whole effect of the parallaxes (both in longitude and latitude) on the duration of the transit at Bencoolen.

But the duration as seen at the mouth of the Ganges, from ingress to egress, is still less; for it is only 5 hours 42 minutes 4 seconds: which is 9 minutes 56 seconds less than as seen from the Earth's centre, and 4 minutes 34 seconds less than as seen at Bencoolen.

482. The island of St. Helena (to which only a small part of the transit is visible at the end), will be at *H* (as in Fig 4) when the egress begins as seen from the Earth's centre And since the middle of that island is 6° west from the meridian of London, and the said egress begins when the time at London is 20 minutes past VIII in the morning, it will then be only 56 minutes past VII in the morning at St. Helena.

Draw *H n* parallel to Venus's orbit *V C O*, and *H o* perpendicular to it; and by measuring them on the scale *A B* (Fig. 3), the former will be found to amount to 29″ for Venus's eastern parallax in longitude, as seen from St. Helena, when her egress begins, as seen from the Earth's centre; and the latter to be 6″ for her northern parallax in latitude at that time. Fig 3.

By the analogy in § 476, this parallax of longitude gives 10 minutes 2 seconds of time; which being added (on account of its being eastward) to 7 hours 56 minutes, gives 8 hours 6 minutes 2 seconds for the beginning of egress at St. Helena, as affected by this parallax. But 6″ of parallax in latitude (applied as in the case of Bencoolen) lengthens out the end of the transit-line by one minute; which being added to 8 hours 6 minutes 2 seconds, gives 8 hours 7 minutes 2 seconds, for the beginning of egress, as seen from St. Helena.

483. We shall now collect the above-mentioned times into a small table, that they may be seen at once, as follows. M signifies morning, A afternoon.

	Total Ingress.				Beg. of Egress.				Duration.		
	H.	M.	S.		H.	M.	S.		H.	M.	S.
The Earth's centre	2	28	0	M	8	20	0	M	5	52	0 [s]
London	Invisible			M	8	17	41	M	—	—	—
The Ganges mouth	8	30	15	M	2	12	19	A	5	42	4
Bencoolen	9	19	30	M	3	6	8	A	5	46	38
St. Helena	Invisible			M	8	7	2	M	—	—	—

484. The times at the three last-mentioned places are reduced to the meridian of London, by subtracting 5 hours 56 minutes from the time of ingress and egress at the Ganges: 6 hours 48 minutes from the times thereof at Bencoolen; and adding 24 minutes to the time of beginning of egress at St. Helena; and being thus reduced, they are as follows:— Method of projecting transits.

		Total Ingress.				Beg. of Egress.				
		H.	M.	S.		H.	M.	S.		
Times at London for	Ganges mouth	2	34	15	M	8	16	19	M	Durations as above.
	Bencoolen	2	31	30	M	8	18	8	M	
	St. Helena	Invisible			M	8	31	2	M	

485. All this is on the supposition, that we have the true longitudes of the three last-mentioned places, that the Sun's horizontal parallax is $12\frac{1}{2}''$, that the true latitude of Venus is given, and that her semidiameter will subtend an angle of $37\frac{1}{2}''$ on the Sun's disc.

As for the longitudes, we must suppose them true, until the observers ascertain them, which is a very important part of their business; and without which they can by no means find the interval of absolute time that elapses between either the ingress or egress, as seen from any two given places: and there is much greater dependence to be had on this elapse, than upon the

[s] This duration, as seen from the Earth's centre, is on the supposition that the semidiameter of Venus would be found equal to $37\frac{1}{2}''$, on the Sun's disc, as stated by Dr. Halley (see Art. V, § 453), to which all the other durations are accommodated. —But, from later observations, it is highly probable, that the semidiameter of Venus will be found not to exceed $30''$ on the Sun: and if so, the duration between the two internal contacts, as seen from the Earth's centre, will be 5 hours 58 minutes; and the durations, as seen from the above-mentioned places, will be lengthened very nearly in the same proportion.

whole contraction of duration at any given place, as it will undoubtedly afford a surer basis for determining the Sun's parallax.

486. I have good reason to believe, that the latitude of Venus, as given in § 453, will be found by observation to be very near the truth, but that the time of conjunction there mentioned will be found later than the true time by almost 5 minutes, that Venus's semidiameter will subtend an angle of no more than 30″ on the Sun's disc; and that the middle of her transit, as seen from the Earth's centre, will be at 24 minutes after V in the morning, as reckoned by the equal time at London.

487. Subtract 8 hours 17 minutes 41 seconds, the time when the egress begins at London, from 8 hours 31 minutes 2 seconds, the time reckoned at London when the egress begins at St Helena, and there will remain 13 minutes 21 seconds (or 801 seconds) for their difference, or elapse, in absolute time, between the beginning of egress as seen from these two places.

Divide this elapse of 801 seconds by the Sun's parallax $12\frac{1}{2}''$, and the quotient will be 64 seconds and a small fraction So that for each second of a degree in the Sun's horizontal parallax (supposing it to be $12\frac{1}{2}''$), there will be a difference or elapse of 64 seconds of absolute time between the beginning of egress as seen from London, and as seen from St Helena · and consequently 32 seconds of time for every half second of the Sun's parallax; 16 seconds of time for every fourth part of a second of the Sun's parallax; 8 seconds of time for the eighth part of a second of the Sun's parallax, and full 4 seconds for a sixteenth part of the Sun's parallax

For, in so small an angle as that of the Sun's parallax, the arc is not sensibly different from either its sine or its tangent: and therefore, the quantity of this parallax is in direct proportion to the absolute difference in the time of egress arising from it, at different parts of the Earth.

488. Therefore, when this difference is ascertained by good observations, made at different places, and compared together, the true quantity of the Sun's parallax will be very nearly determined. For, since it may be presumed that the beginning of egress can be observed within 2 seconds of its real time, the Sun's parallax may be then found within the 32d part of a se-

cond of its true quantity; and consequently his distance may be found within a 400th part of the whole, provided his parallax be not less than 12½″; for 32 times 12½ is 400.

489. But since Dr. Halley has assured us, that he had observed the two internal contacts of the planet Mercury with the Sun's edge so exactly, as not to err one second in the time thereof, we may well imagine that the internal contacts of Venus with the Sun may be observed with as great accuracy. So that we may hope to have the absolute interval between the moments of her beginning of egress, as seen from London and from St. Helena, true to a second of time; and if so, the Sun's parallax may be determined to the 64th part of a second, provided it be not less than 12½″; and consequently his distance may be found, within its 800th part, for 64 times 12½ is 800; which is still nearer the truth than Dr. Halley expected it might be found, by observing the whole duration of the transit in the East Indies and at Port-Nelson. So that our present astronomers have judiciously resolved to improve the Doctor's method, by taking only the interval between the absolute times of its ending at different places. If the Sun's parallax be greater or less than 12½″, the elapse or difference of absolute time between the beginning of egress at London and St. Helena will be found by observation to be greater or less than 801 seconds accordingly.

490. There will also be a great difference between the absolute times of egress at St. Helena and the northern parts of Russia, which would make these places very proper for observation. The difference between them at Tobolsk in Siberia and at St. Helena will be 11 minutes, according to de L'Isle's map: at Archangel it will be but about 40 seconds less than at Tobolsk; and only a minute and a quarter less at Petersburgh, even if the Sun's parallax be no more than 10½″. At Wardhus the same advantage would nearly be gained as at Tobolsk; but if the observers could go still farther to the east, as to Yakoutsk in Siberia, the advantage would be still greater; for, as M. de L'Isle very justly observes, in a memoir presented to the French king with his map of the transit, the difference of time between Venus's egress from the Sun at Yakoutsk and at the Cape of Good Hope will be 13¼ minutes

491. This method requires that the longitude of each place of observation be ascertained to the greatest degree of nicety,

and that each observer's clock be exactly regulated to the equal time at his place: for without these particulars it would be impossible for the observers to reduce the times to those which are reckoned under any given meridian; and without reducing the observed times of egress at different places to the time at some given place, the absolute time that elapses between the egress at one place and at another could not be found. But the longitudes may be found, by observing the eclipses of Jupiter's satellites; and a true meridian for regulating the clock, to the time at any place, may be had, by observing when any given star, within 20 or 30 degrees of the pole, is stationary, with regard to its azimuth, on the east and west sides of the pole; the pole itself being the middle point between these two stationary positions of the star. And it is not material for the observers to know exactly either the true angular measure of the Sun's diameter, or of Venus's, in this case; for whatever their diameters be, it will make no sensible difference in the observed interval between the same contact, as seen from different places.

Plate XVI. Fig. 3. 492. In the geometrical construction of transits, the scale *A B* may be divided into any given number of equal parts, answering to any assumed quantity of Venus's horizontal parallax from the Sun (which is always the difference between the horizontal parallax of Venus and that of the Sun), provided the whole length of the scale be equal to the semidiameter of the Earth's disc in Fig. 4. Thus, if Fig. 4. we suppose Venus's horizontal parallax from the Sun to be only 26″ (instead of 31″), in which case the Sun's horizontal parallax must be 10.3193″, as in § 20, the rest of the projection will answer to that scale: as *C D*, which contains only 26 equal parts, is the same length as *A B*, which contains 31. And by working in all other respects as taught from § 467 to § 483, you will find the times of total ingress and beginning of egress; and, consequently, the duration of the transit at any given place, which must result from such a parallax.

493. In projections of this kind, it may be easily conceived, that a right line passing continually through the centre of Venus, and a given point of the Earth, and produced to the Sun's disc, will mark the path of Venus on the Sun as seen from the given point of the Earth; and in this there are three

cases. 1, When the given point is the Earth's centre, at which there is no parallax, either in longitude or latitude. 2, When the given point is one of the poles, where there is no parallax of longitude; but a parallax of latitude, whose quantity is easily determined, by letting fall a perpendicular from the pole upon the plane of Venus's orbit, and setting off the parallax of latitude on this perpendicular: and here, the polar transit-lines will be parallel to the central; as the poles have no motion arising from the Earth's diurnal rotation. 3, The last case is, when the given point of the Earth is any point of its surface, whose latitude is less than 90 degrees: then there is a parallax in latitude proportional to the perpendicular let fall upon the above-mentioned plane, from the given point; and a parallax in longitude proportional to the perpendicular let fall upon the axis of that plane, from the said given point. And the effect of this last will be to alter the transit-line, both in position and length; and will prevent its being parallel to the central transit-line, unless when its axis and the axis of the Earth coincide, as seen from the Sun; which is a thing that may not happen in many ages.

ART. VI.—*Concerning the map of the transit.*—Plate XVII.

494. The title of this map, and the lines drawn upon it, together with the words annexed to these lines, and the numbers (hours and minutes) on the dotted lines, explain the whole of it so well, that no farther description seems requisite.

Concerning the map of the transit, Plate XVII.

495. So far as I can examine the map by a good globe, the black curve lines are in general pretty well laid down, for shewing at what places the transit will begin, or end, at sun-rising or sun-setting, to all those places through which they are drawn, according to the times mentioned in the map. Only I question much whether the transit will begin at sun-rise to any place in Africa, that is west of the Red Sea; and am pretty certain that the Sun will not be risen to the northmost part of Madagascar when the transit begins, as M. de L'Isle reckons the first contact of Venus with the Sun to be the beginning of the transit. So that the line which shews the entrance of Venus on the Sun's disc at sun-rising, seems to be a little too far west in the

map, at all places which are south of Asia Minor: but in Europe, I think it is very well.

496. In delineating this map, I had M. de L'Isle's map of the transit before me; and the only difference between his map and this is; 1, That in his map, the times are computed to the meridian of Paris; in this they are reduced to the meridian of London. 2, I have changed his meridional projection into that of the equatoreal; by which, I apprehend, that the black curve lines, shewing at what places the transit begins or ends, with the rising or setting Sun, appear more natural to the eye, and are more fully seen at once, than in the map from which I copied; for, in that map, the lines are interrupted and broken in the meridian that divides the hemispheres, and the places where they should join cannot be perceived so readily by those who are not well skilled in the nature of stereographical projections. The like may be said of many of the dotted curve lines, on which are expressed the hours and minutes of the beginning or ending of the transit, which are the absolute times at these places through which the lines are drawn, computed to the meridian of London.

ART. VII.—*Containing an Account of Mr. Horrox's Observation of the Transit of Venus over the Sun, in the Year* 1639; *as it is published in the Annual Register for the Year* 1761.

Kepler first predicts the transits of Venus and Mercury.

497. When Kepler first constructed his (the Rudolphine) tables upon the observations of Tycho, he soon became sensible that the planets Mercury and Venus would sometimes pass over the Sun's disc; and he predicted two transits of Venus, one for the year 1631, and the other for 1761, in a tract published at Leipsic in 1629, entitled *Admonitio ad Astronomos, &c.* Kepler died some days before the transit in 1631, which he had predicted was to have happened. Gassendi looked for it at Paris, but in vain (see *Mercurius in Sole visus, et Venus invisa*). Indeed, the imperfect state of the Rudolphine tables was the cause that the transit was expected in 1631, when none could be observed; and those very tables did not give reason to expect one in 1639, when one was really observed.

498. When our illustrious countryman Mr. Horrox first applied himself to astronomy, he computed Ephemerides for several years, from Lansbergius's tables. After continuing his labours for some time, he was enabled to discover the imperfection of these tables; upon which he laid aside his work, intending to determine the positions of the stars from his own observations. But, that the former part of his time spent in calculating from Lansbergius might not be thrown away, he made use of his Ephemerides to point out to him the situations of the planets. Hence he foresaw when their conjunctions, their appulses to the fixed stars, and the most remarkable phenomena in the heavens, would happen; and prepared himself with the greatest care to observe them.

Horrox discovers the imperfection of the planetary tables.

499. From this he was encouraged to wait for the important observation of the transit of Venus in the year 1639; and no longer thought the former part of his time misspent, since his attention to Lansbergius's tables had enabled him to discover that the transit would certainly happen on the 24th of November. However, as these tables had so often deceived him, he was unwilling to rely on them entirely, but consulted other tables, and particularly those of Kepler: accordingly, in a letter to his friend William Crabtree of Manchester, dated Hool, October 26, 1639, he communicated his discovery to him, and earnestly desired him to make whatever observations he possibly could with his telescope, particularly to measure the diameter of the planet Venus, which, according to Kepler, would amount to 7 minutes of a degree, and according to Lansbergius to 11 minutes; but which, according to his own proportion, he expected would hardly exceed one minute He adds, that according to Kepler, the conjunction will be November 24, 1639, at 8 hours 1 minute A. M. at Manchester, and that the planet's latitude would be 14′ 10″ south; but according to his own corrections he expected it to happen at 3 hours 57 minutes P. M. at Manchester, with 10′ south latitude. But because a small alteration in Kepler's numbers would greatly alter the time of conjunction, and the quantity of the planet's latitude, he advises to watch the whole day, and even on the preceding afternoon, and the morning of the 25th, though he was entirely of opinion that the transit would happen on the 24th.

Determines to observe the transit of Venus in 1639.

500. After having fully weighed and examined the several methods of observing this uncommon phenomenon, he determined to transmit the Sun's image through a telescope into a dark chamber, rather than through a naked aperture, a method greatly commended by Kepler; for the Sun's image is not given sufficiently large and distinct by the latter, unless at a very great distance from the aperture, which the narrowness of his situation would not allow of; nor would Venus's diameter be well defined, unless the aperture were very small; whereas his telescope, which rendered the solar spots distinctly visible, would shew him Venus's diameter well defined, and enable him to divide the Sun's limb more accurately.

Horrox's method of observing transits.

501. He described a circle on paper which nearly equalled six inches, the narrowness of the place not allowing a larger size; but even this size admitted divisions sufficiently accurate. He divided the circumference into 360 degrees, and the diameter into 30 equal parts, each of which were subdivided into 4, and the whole therefore into 120. The subdivision might have still been carried farther, but he trusted rather to the accuracy and niceness of his eye.

His observations on the transit of 1639.

502. When the time of observation drew near, he adjusted the apparatus, and caused the Sun's distinct image exactly to fill the circle on the paper; and though he could not expect the planet to enter upon the Sun's disc before three o'clock in the afternoon of the 24th, from his own corrected numbers, upon which he chiefly relied; yet, because the calculations in general from other tables gave the time of conjunction much sooner, and some even on the 23d, he observed the Sun from the time of its rising to nine o'clock; and again, a little before ten; at noon, and at one in the afternoon: being called in the intervals to business of the highest moment, which he could not neglect. But in all these times he saw nothing on the Sun's face, except one small spot, which he had seen on the preceding day; and which also he afterward saw on some of the following days.

503. But at 3 hours 15 minutes in the afternoon, which was the first opportunity he had of repeating his observations, the clouds were entirely dispersed and invited him to seize this favourable occasion, which seemed to be providentially thrown in his way; for he then beheld the most agreeable sight, a spot

which had been the object of his most sanguine wishes, of an unusual size, and of a perfectly circular shape, just wholly entered upon the Sun's disc on the left side; so that the limbs of the Sun and Venus perfectly coincided in the very point of contact. He was immediately sensible that this spot was the planet Venus, and applied himself with the utmost care to prosecute his observations.

504. And, *First*, With regard to the inclination, he found, by means of a diameter of the circle set perpendicular to the horizon, the plane of the circle being somewhat reclined on account of the Sun's altitude, that Venus had wholly entered upon the Sun's disc, at 3 hours 15 minutes, at about 62 degrees 30 minutes, (certainly between 60 and 65 degrees) from the vertex toward the right hand. (These were the appearances within the dark chamber, where the Sun's image and motion of the planet thereon were both inverted and reversed.) And this inclination continued constant, at least to all sense, till he had finished the whole of his observation. Inclination of Venus's path.

505. *Secondly*, The distances observed afterwards between the centres of the Sun and Venus were as follow:—At 3 hours 15 minutes by the clock, the distance was 14′ 24″, at 3 hours 35 minutes, the distance was 13′ 30″; and at 3 hours 45 minutes, the distance was 13′. The apparent time of sun-setting was at 3 hours 50 minutes—the true time 3 hours 45 minutes—refraction keeping the sun above the horizon for the space of 5 minutes. Distances between the centres of the Sun and Venus.

506. *Thirdly*, He found Venus's diameter, by repeated observations, to exceed a thirtieth part of the Sun's diameter, by a sixth, or at most a fifth subdivision. The diameter therefore of the Sun to that of Venus may be expressed as 30 to 1.12. It certainly did not amount to 1.30, nor yet to 1.20. And this was found by observing Venus as well when near the Sun's limb, as when farther removed from it. Diameter of Venus.

507. The place where this observation was made, was an obscure village called Hool, about 15 miles northward of Liverpool. The latitude of Liverpool had been often determined by Horrox to be 53° 20′; and therefore that of Hool will be 53° 35′. The longitude of both seemed to him to be about 22° 30′ from the Fortunate Islands; that is, 14° 15′ to the west of Uraniburg.

508. These were all the observations which the shortness of the time allowed him to make upon this most remarkable and uncommon sight: all that could be done, however, in so small a space of time, he very happily executed; and scarcely anything farther remained for him to desire. In regard to the inclination alone, he could not obtain the utmost exactness; for it was extremely difficult, from the Sun's rapid motion, to observe it to any certainty within the degree; and he ingenuously confesses that he neither did nor could possibly perform it. The rest are very much to be depended upon, and as exact as he could wish.

Mr. Crabtree observes the transit in 1639.

509. Mr. Crabtree, at Manchester, whom Mr. Horrox had desired to observe this transit, and who in mathematical knowledge was inferior to few, readily complied with his friend's request: but the sky was very unfavourable to him, and he had only one sight of Venus on the Sun's disc, which was about 3 hours 35 minutes by the clock, the Sun then, for the first time, breaking out from the clouds; at which time he sketched Venus's situation upon paper, which Horrox found to coincide with his own observations.

510. Mr. Horrox, in his treatise on this subject, published by Hevelius, and from which almost the whole of this account has been collected, hopes for pardon from the astronomical world for not making his intelligence more public; but his discovery was made too late. He is desirous, however, in the spirit of a true philosopher, that other astronomers were happy enough to observe it, who might either confirm or correct his observations. But such confidence was reposed in the tables at that time, that it does not appear that this transit of Venus was observed by any besides our two ingenious countrymen, who prosecuted their astronomical studies with such eagerness and precision, that they must very soon have brought their favourite science to a degree of perfection unknown at those times. But unfortunately Mr. Horrox died on the 3d of January 1640–1, about the age of 25, just after he had put the last hand to his treatise, entitled *Venus in Sole visa*, in which he shews himself to have had a more accurate knowledge of the dimensions of the solar system than his learned commentator Hevelius.—*So far the Annual Register*

511. In the year 1691 (See the *Connoissance des Temps* for 1761), Dr. Halley gave in a paper upon the transit of Venus (See *Lowthorpe's Abridgment of the Philosophical Transactions*, page 434), in which he observes, from the tables then in use, that Venus returns to a conjunction with the Sun in her ascending node in a period of 18 years, wanting 2 days 10 hours 52½ minutes; but that, in the second conjunction, she will have got 24′ 41″ farther to the south than in the preceding.' That after a period of 235 years 2 hours 10 minutes 9 seconds, she returns to a conjunction more to the north by 11′ 33″; and after 243 years, wanting 43 minutes, in a point more to the south, by 13′ 8″. But if the second conjunction is in the year next after leap-year, it will be a day later

Dr. Halley predicts several transits of Venus.

512 The intervals of the conjunctions at the descending node are somewhat different. The second happens in a period of 8 years, wanting 2 days 6 hours 55 minutes, Venus being got more to the north by 19′ 58″. After 235 years 2 days 8 hours 18 minutes, she is 9′ 21″ more southerly; only, if the first year is a bissextile, a day must be added. And after 243 years 0 days 1 hour 23 minutes, the conjunction happens 10′ 37″ more to the north; and a day later, if the first year was bissextile. It is supposed, as in the old style, that all the centurial years are bissextiles.

513. Hence Dr. Halley finds the years in which a transit may happen at the ascending node, in the month of November (old style) to be these—918, 1161, 1396, 1631, 1639, 1874, 2109, 2117: and the transits in the month of May (old style) at the descending node, to be in these years—1048, 1283, 1518, 1526, 1761, 1769, 1996, 2004.

514. In the first case, Dr. Halley makes the visible inclination of Venus's orbit to be 9° 5′, and her horary motion on the Sun 4′ 7″. In the latter, he finds her visible inclination to be 8′ 28″, and her hororary motion 4′. In either case, the greatest possible duration of a transit is 7 hours 56 minutes.

515. Dr Halley could even then conclude, that if the interval in time between the two interior contacts of Venus with the Sun could be measured to the exactness of a second, in two places properly situated, the Sun's parallax might be determined within its 500th part. But several years after, he explained this affair more fully, in a paper concerning the transit of Venus in the year 1761, which was published in the

Philosophical Transactions, and of which the third of the preceding articles is a translation, the original having been written in Latin by the doctor.

Art. VIII.—*Containing a short Account of some Observations of the Transit of Venus,* A. D. 1761, *June* 6, *New Style; and the Distances of the Planets from the Sun, as deduced from those Observations.*

Dr. Bliss's observations on the transit in 1761.

516. Early in the morning, when every astronomer was prepared for observing the transit, it unluckily happened, that both at London and the royal observatory at Greenwich, the sky was so overcast with clouds as to render it doubtful whether any part of the transit should be seen; and it was 38 minutes 21 seconds past VII o'clock (apparent time) at Greenwich, when the Reverend Dr. Bliss, our astronomer-royal, first saw Venus on the Sun; at which instant the centre of Venus preceded the Sun's centre by 6′ 18.9″ of right ascension, and was south of the Sun's centre by 18′ 42.1″ of declination. From that time to the beginning of egress, the doctor made several observations, both of the difference of right ascension and declination of the centres of the Sun and Venus: and at last found the beginning of egress, or instant of the internal contact of Venus with the Sun's limb, to be at 8 hours 19 minutes apparent time. From the doctor's own observations, and those which were made at Shirburn by another gentleman, he has computed, that the mean time at Greenwich of the ecliptical conjunction of the Sun and Venus was at 51 minutes 20 seconds after V o'clock in the morning; that the place of the Sun and Venus was ♊ (*Gemini*) 15 36′ 33″; and that the geocentric latitude of Venus was 9′ 44.9″ south; her horary motion from the Sun 3′ 57.13″ retrograde; and the angle then formed by the axis of the equator, and the axis of the ecliptic, was 6° 9′ 34″, decreasing hourly 1 minute of a degree. By the mean of three good observations, the diameter of Venus on the Sun was 58″.

Mr. Short's observations on the transit.

517. Mr. Short made his observation at Savile-house, in London, 20 seconds in time west from Greenwich, in presence of his royal highness the duke of York, accompanied by their royal high-

nesses Prince William, Prince Henry, and Prince Frederick. He first saw Venus on the Sun, through flying clouds, at 46 minutes 37 seconds after V o'clock; and at 6 hours 15 minutes 12 seconds, he measured the diameter of Venus 59.8″. He afterwards found it to be 58.9″ when the sky was more favourable. And, through a reflecting telescope of two feet focus, magnifying 140 times, he found the internal contact of Venus with the Sun's limb to be at 8 hours 18 minutes 21½ seconds, apparent time; which, being reduced to the apparent time at Greenwich, was 8 hours 18 minutes 51½ seconds; so that his time of seeing the contact was 8½ seconds sooner (in absolute time) than the instant of its being seen at Greenwich.

Messrs. Ellicot and Dollond's observations.

518. Messrs. Ellicot and Dollond observed the internal contact at Hackney, and their time of seeing it, reduced to the time at Greenwich, was at 8 hours 18 minutes 56 seconds, which was 4 seconds sooner in absolute time than the contact was seen at Greenwich.

Mr. Canton's observations.

519. Mr. Canton, in Spittal-square, London, 4′ 11″ west of Greenwich (equal to 16 seconds 44 thirds of time) measured the Sun's diameter 31′ 33″ 24‴, and the diameter of Venus on the Sun 58″; and, by observation, found the apparent time of the internal contact of Venus with the Sun's limb to be at 8 hours 18 minutes 41 seconds; which, by reduction, was only 2¼ seconds short of the time at the royal observatory of Greenwich.

Mr. Haydon's observations.

520. The Reverend Mr. Richard Haydon, at Liskeard, in Cornwall (16 minutes 10 seconds in time west from London, as stated by Dr. Bevis) observed the internal contact to be at 8 hours 20 seconds, which, by reduction, was 8 hours 16 minutes 30 seconds at Greenwich; so that he must have seen it 2 minutes 30 seconds sooner in absolute time than it was seen at Greenwich—a difference by much too great to be occasioned by the difference of parallaxes. But, by a memorandum of Mr. Haydon's some years before, it appears that he then supposed his west longitude to be near 2 minutes more, which brings his time to agree within half a minute of the time at Greenwich; to which the parallaxes will very nearly answer.

Mr. Wargentin's observations.

521. At Stockholm observatory, latitude 59° 20½′ north, and longitude 1 hour 12 minutes east from Greenwich, the whole of the transit was visible; the total ingress was observed by Mr. Wargentin to be at 3 hours 39 minutes 23 seconds in the morning, and the beginning of the egress at 9 hours 30 minutes 8 seconds; so that the whole duration between the two internal contacts, as seen at that place, was 5 hours 50 minutes 45 seconds.

Mr. Hellant's observations.

At Torneo in Lapland (1 hour 27 minutes, 28 seconds east of Paris) Mr. Hellant, who is esteemed a very good observer, found the total ingress to be at 4 hours 3 minutes 59 seconds; and the beginning of egress to be 9 hours 45 minutes 8 seconds,—so that the whole duration between the two internal contacts was 5 hours 50 minutes 9 seconds.

Mr. Gister's observations.

At Hernosand, in Sweden (latitude 6 38 north, and longitude 1 hour 2 minutes 12 seconds east of Paris), Mr. Gister observed the total ingress to be at 3 hours 38 minutes 26 seconds; and the beginning of egress to be at 9 hours 29 minutes 21 seconds,—the duration between these two internal contacts 5 hours 50 minutes 56 seconds.

Mr. de la Lande's observations.
Mr. Ferner's observations.

Mr. de la Lande, at Paris, observed the beginning of egress to be at 8 hours 28 minutes 26 seconds apparent time. But Mr. Ferner (who was then at Conflans, 14½″ west of the royal observatory at Paris) observed the beginning of egress to be at 8 hours 28 minutes 29 seconds true time. The equation, or difference between the true and apparent time, was 1 minute 54 seconds. The total ingress, being before the Sun rose, could not be seen.

Mr Chappe's observations.

At Tobolsk, in Siberia, Mr. Chappe observed the total ingress to be at 7 hours 28 seconds in the morning, and the beginning of egress to be at 49 minutes 20½ seconds after XII at noon. So that the whole duration of the transit between the internal contacts was 5 hours 48 minutes 52½ seconds, as seen at that place: which was 2 minutes 3½ seconds less than as seen at Hernosand in Sweden.

Mr. Hirst's observations.

At Madras, the Reverend Mr. Hirst observed the total ingress to be at 7 hours 47 minutes 55 seconds apparent time in the morning; and the beginning of egress at 1 hour 39 minutes 38 seconds past noon. The duration be

tween these two internal contacts was 5 hours 51 minutes 43 seconds.

Professor Mathenci's observations.

Professor Mathenci at Bologna observed the beginning of egress to be at 9 hours 4 minutes 58 seconds.

Mr. Magee's observations.

At Calcutta (latitude 22° 30′ north, nearly 92° east longitude from London) Mr. William Magee observed the total ingress to be at 8 hours 20 minutes 58 seconds in the morning, and the beginning of egress to be at 2 hours 11 minutes 34 seconds in the afternoon. The duration between the two internal contacts 5 hours 50 minutes 36 seconds.

Mr. Mason's observations.

At the Cape of Good Hope (1 hour 13 minutes 35 seconds east from Greenwich) Mr. Mason observed the beginning of egress to be at 9 hours 39 minutes 50 seconds in the morning.

All these times are collected from the observers' accounts, printed in the Philosophical Transactions for the year 1762 and 1763, in which there are several other accounts that I have not transcribed. The instants of Venus's total exit from the Sun are likewise mentioned, but they are here left out, as not being of any use for finding the Sun's parallax.

Whoever compares these times of the internal contacts, as given by different observers, will find such difference among them, even those which were taken upon the same spot, as will shew, that the instant of either contact could not be so accurately perceived by the observers as Dr. Halley thought it could: which probably arises from the difference of people's eyes, and the different magnifying powers of those telescopes through which the contacts were seen. If all the observers had made use of equal magnifying powers, there can be no doubt but that the times would have more nearly coincided; since it is plain, that supposing all their eyes to be equally quick and good, they whose telescopes magnified most would perceive the point of internal contact soonest, and of the total exit latest.

Mr. Short has taken an incredible deal of pains in deducing the quantity of the Sun's parallax, from the best of those observations which were made both in Britain and abroad: and finds it to have been 8″.52 on the day of the transit, when the Sun

was very nearly at his greatest distance from the Earth; and consequently 8″.65 when the Sun is at his mean distance from the Earth. And indeed, it would be very well worth every curious person's while, to purchase the second part of Volume LII of the Philosophical Transactions, for the year 1763; even if it contained nothing more than Mr. Short's paper on that subject.

The logarithm sine (or tangent) of 8″.65 is 5.6219140, which being subtracted from the radius 10.0000000, leaves remaining the logarithm 4.3780860, whose number is 23882.34; which is the number of semidiameters of the Earth that the Sun is distant from it. And this last number, 23882.34, being multiplied by 3985, the number of English miles contained in the Earth's semidiameter, gives 95,173,127 miles for the Earth's mean distance from the Sun. But because it is impossible, from the nicest observations of the Sun's parallax, to be sure of its true distance from the Earth within 100 miles, we shall at present, for the sake of round numbers, state the Earth's mean distance from the Sun at 95,173,000 English miles.

And then, from the numbers and analogies in § 420 and 421, p. 32, 33, vol. II, we find the mean distances of all the rest of the planets from the Sun in miles to be as follows. Mercury's distance, 36,841,468; Venus's distance, 68,891,486; Mars's distance, 145,014,148; Jupiter's distance, 494,990,976; and Saturn's distance, 907,957,130.[9]

So that, by comparing these distances with those in the tables at the end of the chapter on the solar system, it will be found that the dimensions of the system are much greater than what was formerly imagined; and consequently, that the Sun and all the planets, except the Earth, are much larger than as stated in that table.

The semidiameter of the Earth's annual orbit being equal to the Earth's mean distance from the Sun, viz. 95,173,000 miles, the whole diameter thereof is 190,346,000 miles. And since the circumference of a circle is to its diameter as 355 is to 113, the circumference of the Earth's orbit is 697,937,646 miles.

[9] When I computed the distances in the last line of § 194, I had heard that the Sun's parallax was found to be 8″.69; which occasions the difference between these distances and those which arise here from the parallax 8″.65, as I found it in the Philosophical Transactions.

And, as the Earth describes this orbit in 365 days 6 hours (or in 8766 hours), it is plain that it travels at the rate of 68,217 miles every hour, and consequently 11,369 miles every minute; so that its velocity in its orbit is at least 142 times as great as the velocity of a cannon ball, supposing the ball to move through 8 miles in a minute, which it is found to do very nearly. and at this rate it would take 22 years 228 days for a cannon ball to go from the Earth to the Sun.

On the 3d of June, in the year 1769, Venus will again pass over the Sun's disc, in such a manner as to afford a much easier and better method of investigating the Sun's parallax than her transit in the year 1761 has done. But no part of Britain will be proper for observing that transit, so as to deduce any thing with respect to the Sun's parallax from it, because it will begin but a little before sun-set, and will be quite over before II o'clock next morning. The apparent time of conjunction of the Sun and Venus, according to Dr. Halley's Tables, will be at 13 minutes past X o'clock at night at London; at which time the geocentric latitude of Venus will be fully 10 minutes of a degree north from the Sun's centre: and therefore, as seen from the northern parts of the Earth, Venus will be considerably depressed by a parallax of latitude on the Sun's disc; on which account, the visible duration of the transit will be lengthened: and in the southern parts of the Earth she will be elevated by a parallax of latitude on the Sun, which will shorten the visible duration of the transit, with respect to its duration as supposed to be seen from the Earth's centre; to both which affections of duration the parallaxes of longitude will also conspire. So that every advantage which Dr. Halley expected from the late transit will be found in this without the least difficulty or embarrassment. It is therefore to be hoped, that neither cost nor labour will be spared in duly observing this transit; especially as there will not be such another opportunity again in less than 105 years afterward.

The most proper places for observing the transit in the year 1769 is in the northern part of Lapland, and the Solomon Isles in the Great South Sea; at the former of which the visible duration between the two internal contacts will be at least 22 minutes greater than at the latter, even though the Sun's parallax should not be quite 9″. If it be 9″ (which is the quantity I had

assumed in a delineation of this transit, which I gave in to the Royal Society before I had heard what Mr. Short had made it from the observations on the late transit), the difference of the visible durations, as seen in Lapland and in the Solomon Isles, will be as expressed in that delineation, and if the Sun's parallax be less than 9″ (as I now have very good reason to believe it is), the difference of durations will be less accordingly.

SUPPLEMENTARY CHAPTERS

TO

FERGUSON'S ASTRONOMY,

BY

THE EDITOR.

Me hercules non aliud quis aut magnificentius quæsierit, aut didicerit utilius quam de stellarum siderumque natura."

SENECA, Cap I, *De Cometis.*

SUPPLEMENTARY CHAPTERS

FERGUSON'S ASTRONOMY.

CHAP. I.

ON THE FIVE NEW PLANETS, THE GEORGIUM SIDUS, CERES, PALLAS, JUNO, AND VESTA.

The great additions which astronomy has lately received, have given a new form to this interesting science, and extended our knowledge far beyond the limits of the system which we inhabit. The discovery of five primary, and eight secondary planets; the determination of the motion of our system in free space; the reference of all the celestial phenomena, and particularly of the inequalities arising from the mutual action of the planets, to the simple law of gravitation; and the consequent improvement of our astronomical tables, form a lasting monument to the industry and genius of their authors, and mark the close of the first, and the commencement of the present century, as the most brilliant period in the history of astronomy.

For several of these important discoveries, we are indebted to the powerful telescopes of Sir William Herschel, by which he detected two of the satellites of Saturn, and all the satellites of the Georgium Sidus. The success of this celebrated astronomer gave birth to a spirit of observation and inquiry which was before unknown. The heavens have been explored with the most unwearied assiduity, and this laudable zeal for the advancement of astronomy has been crowned with the discovery of *Four new Planets.*

These additions to the science do not merely present us with

a few insulated facts similar to those with which we were formerly acquainted: They exhibit to us new and unexpected phenomena, which destroy that harmony in the solar system which appeared in the magnitudes and distances of the planets, and in the form and position of their orbits. The six planets which formerly composed the system, were placed at somewhat regular distances from the Sun: They moved from west to east, and at such intervals as to prevent any extraordinary derangements which might arise from their mutual action. Their magnitudes, too, with the exception of Saturn, increased with their distance from the centre of the system, and the eccentricity, as well as the inclination of their orbits, was comparatively small. In the present system, however, we find four very small planets between the orbits of Mars and Jupiter, placed at nearly the same distance from the Sun, and moving in very eccentric orbits which intersect each other, and are greatly inclined to the plane of the ecliptic. The satellites of the Georgium Sidus, too, appear to move nearly at right angles to the plane of his orbit; and what is still more surprising, the direction of their motion seems to be opposite to that in which all the other planets, whether primary or secondary, circulate round their respective centres

On the Georgium Sidus.

From inequalities in the motion of Jupiter and Saturn, which could not be accounted for from the mutual action of these planets, it was inferred by some astronomers that there existed beyond the orbit of Saturn another planet, by whose action these irregularities were produced. This happy conjecture was confirmed on the 13th March 1781, when Dr. Herschel discovered a new planet, which, in compliment to his royal patron, he called the *Georgium Sidus*, though on the continent it is better known by the names of *Herschel* or *Uranus*. This new planet, which had been formerly observed as a small star by Flamstead and Mayer, and introduced into their catalogues of the fixed stars, is situated beyond the orbit of Saturn, at the distance of 1,800,000,000 miles from the centre of the system, and performs its sidereal revolution round the Sun in 83 years, 150 days, and 18 hours. Its diameter is about 4½ times larger

than that of the Earth, being nearly 35,112 English miles. When seen from the Earth, its apparent diameter, or the angle which it subtends at the eye, is 3″ 32‴, and its mean diameter as seen from the Sun is 4″. As the distance of the Georgium Sidus from the Sun is twice as great as that of Saturn, it can scarcely be distinguished by the naked eye. When the sky, however, is serene, it appears like a fixed star of the fifth magnitude, with a bluish white light, and a brilliancy between that of Venus and the Moon; but with a power of 200 or 300, its disc is visible and well defined.

The want of light arising from the great distance of this planet from the Sun is supplied by six satellites, all of which were discovered by Dr. Herschel. The *first* satellite is 25″.5 distant from its primary, and revolves round it in 5 days, 21 hours, 25 minutes. The *second* satellite is 33″.09 distant from the planet, and performs its revolution in 8 days, 17 hours, 1 minute, 19.18 seconds. The distance of the *third* satellite is 38″.57, and its periodic time 10 days, 23 hours, 4 minutes. The distance of the *fourth* satellite is 44″.23, and the time of its periodical revolution 13 days, 11 hours, 5 minutes 1.5. The distance of the *fifth* satellite is about 1′ 28″.46, and its revolution is completed in 38 days, 1 hour, 49 minutes. The *sixth* satellite is placed at the distance of 2′ 52″.92 from the primary, and will therefore require 107 days, 16 hours, 40 minutes, to complete one revolution. The second and fourth of these satellites were discovered by Dr. Herschel on the 11th January 1787.[1] The other four were discovered in 1790 and 1794, but their distances and periodic times have not been so accurately ascertained as the other two.[2] It is a remarkable circumstance, however, that all the six satellites move in a retrograde direction, and in orbits lying in the same plane, and almost perpendicular to the ecliptic. M. Delambre has found that the inclinations of their orbits are 89° 30′, or 90° 30′, and the ascending node in 5ˢ 21°, or 8ˢ 9°, according as we adopt the first or the second inclination.

According to La Place, the first five satellites of the Georgium Sidus may be retained in their orbits by the action of its equator, and the sixth by the action of the interior satellites;

[1] See the Phil. Transactions for 1787, p. 125; 1788, p. 364.
[2] See Phil. Trans. 1798, Part I, p. 47.

and hence he concludes, that this planet revolves about an axis very little inclined to the ecliptic, and that the time of its diurnal rotation cannot be much less than that of Jupiter or Saturn.[3]

When the Earth is in its perihelion, and the Georgium Sidus in its aphelion, the latter becomes stationary when his elongation or distance from the Sun is 8s 17° 37′, and his retrogradations continue 151d 12h. When the Earth is in its aphelion, and the Georgium Sidus in its perihelion, it becomes stationary at an elongation of 8s 16° 27′, and the retrogradations continue 149d 18h. The following table contains the elements of the orbit of the Georgium Sidus, andother particulars concerning this planet :—

	Days.		Hours.	Min.
Tropical revolution,.............	30637		4	0
Mean distance from the Sun, that of the Earth being 100000,.............................				1908352
Density, that of water being 1, ...				0,[illegible]
Quantity of matter, that of the Earth being 1,...				16.84
Diameter in English miles,.....................				35112
Inclination of its orbit in 1780, ...			46′	20″
Place of aphelion in 1800, ...	11s	16°	30′	31″
Secular motion of aphelion, ...		1°	29′	2″
Eccentricity of its orbit, the mean distance being 100000, ...				90804
Longitude for 1784, ...	3s	14°	43′	18′
Greatest equation of the centre, ...		5°	27′	16″
Longitude of ascending node in 1788, ...	2	12	47	0″
Secular motion of the node, ...		1°	41	35′
Greatest aberration, ...				25″

On Ceres.

The planet Ceres, which is situated between the orbits of Mars and Jupiter, was discovered at Palermo, in Sicily, on the 1st of January 1801, by M. Piazzi, an ingenious astronomer, who has since distinguished himself by his numerous observations on the fixed stars. This new celestial body was then situated in Taurus, and was observed by Piazzi till the 12th of February, when a dangerous illness compelled him to discon-

[3] See *Mecanique Celeste* par La Place, tome ii, p. 381, tome iv. Preface, and p. 190, and *Mem. de L'Institut.* tome iii, p. 123.

tinue his observations. It was, however, again discovered by Dr. Olbers of Bremen, on the 1st of January 1807, nearly in the place where it was expected from the calculations of Baron Zach. The nebula with which it was surrounded gave it the appearance of a comet; and it was in consequence of the suggestion of Professor Bode of Berlin, or of Baron Zach, that Piazzi and other astronomers ranked it among the planetary bodies.

The planet Ceres is of a ruddy colour, though not very deep, and appears about the size of a star of the eighth magnitude. It seems to be surrounded with a large dense atmosphere, and plainly exhibits a disc, when examined with a magnifying power of about 200. From a great number of observations, Schroeter found the atmosphere of Ceres to be 675 English miles high, and he perceived that it was subject to numerous changes. The visible hemisphere was sometimes overshadowed, and at other times it cleared up: so that he thinks there is little chance of discovering the period of its diurnal rotation. The atmosphere of Ceres, like that of the Earth, is very dense near the planet, and becomes rarer at a greater distance, which produces a very singular effect in the variations of its apparent diameter. When Ceres is approaching to the Earth, its diameter increases much more rapidly than it ought to do from the diminution of the distance. This arises, as Schroeter has observed, from the finer exterior strata of its atmosphere becoming visible while it approaches the Earth. A similar phenomenon was observed in the comet of 1799, where the finer and less solid strata of its coma came into view as its proximity to the Earth increased. In moonlight, the rarer strata of Ceres's atmosphere became invisible.

Ceres performs her revolution round the Sun in four years seven months and ten days; and her mean distance from that luminary is nearly 260,000,000 of English miles. The eccentricity of her orbit is a little greater than that of Mercury, while its inclination to the ecliptic exceeds that of all the old planets. The observations which have been hitherto made upon this celestial body do not seem sufficiently correct to enable us to determine its magnitude with any degree of accuracy. According to the measurements of Herschel, the diameter of Ceres does not exceed *one hundred and sixty* miles, while the observations of the German astronomer Schroeter make it 1624 miles. Schroeter accounts for this remarkable difference be-

'tween his measurements and those of Dr. Herschel, by maintaining, that the projection-micrometer used by the English astronomer was placed at too great a distance from the eye, and that he measured only the middle clear part of the nucleus of the planet. Schroeter made a number of experiments on this interesting subject, from which he has concluded, that, for long-sighted eyes, an illuminated projection-disc must not be removed above eight feet from the eye of the observer; and that, when the distance is greater, the diameter of the planet is found too small, by a quantity depending on the increase of distance, on the degree of illumination, and on the state of the observer's eye. When the projection-discs were placed at the distance of 3 feet 9.9 inches, and 4 feet 3.9 inches from the eye, the diameter of Juno was found to be 2.526 seconds; but when a disc, 3.5 inches in diameter, was removed to the distance of 143 feet 4 inches from the observer, the diameter of Juno was found to be only 0.50 seconds,—about five times smaller than it ought to have been.

The following Table presents, at one view, the various particulars which are known respecting the planet Ceres.

	Years.	Months.	Days.	
Tropical revolution, *La Lande*,..	4	7	10	
Do. from Maskelyne's table,.............	1681^d	12^h	9^m	
Annual motion,..................................	2^s	18°	11′	
Mean longitude, January 1, 1818,..	10^s	26°	51′	7″
Place of ascending node in 1818,........................	2^s	20°	45′	1″
Place of perihelion in 1818,......................	4^s	27°	18′	21″
Eccentricity in 1806, the mean distance being 1, according to Westphal,..........................		0 07851589		
Annual diminution,..................		0.0000583		
Inclination of orbit in 1818,..................................		10°	37′	55″
Annual diminution,..				0″.14
Annual motion,.........................				1″.18
Mean distance from the Sun, that of the Sun from the Earth being 1,..		2.768		
Mean distance in English miles,...........................		260.000.000		
Diameter in English miles, *Herschel*,......		163		
Do. do. *Schroeter*, ...		1621		
Do. do. including the atmosphere, ...		2299		
Height of Ceres' atmosphere, ...		677		
Apparent mean diameter, as seen from the Earth, according to Harding, ...			2″.5	
Do. according to Schroeter, comprehending the atmosphere at the mean distance of the Earth.				6″.382
Mean diurnal tropical motion, according to Westphal,				770″.7783
Log. of ½ greater axis,........		0.1421029		

On Pallas.

The planet Pallas, was discovered at Bremen, in Lower Saxony, on the 28th March 1802, by Dr. Olbers, the same active astronomer who rediscovered Ceres. It is situated between the orbits of Mars and Jupiter, and is nearly of the same magnitude with Ceres, but of a less ruddy colour. It is surrounded with a nebulosity of less extent, and performs its annual revolution in nearly the same period. The planet Pallas, however, is distinguished in a very remarkable manner from Ceres and all the other primary planets, by the immense inclination of its orbit. While these bodies are revolving round the Sun in almost circular paths, rising only a few degrees above the plane of the ecliptic, Pallas ascends above this plane at an angle of about 35 degrees, which is nearly four times greater than the inclination of Mercury. From the eccentricity of Pallas being greater than that of Ceres, or from a difference of position in the line of their apsides, while their mean distances are nearly equal, the orbits of these two planets mutually intersect each other—a phenomenon which is altogether anomalous in the solar system.

The atmosphere of Pallas, according to the observations of Schroeter, is to that of Ceres as 101 to 146, or nearly as 2 to 3. It undergoes similar changes, but the light of the planet exhibits greater variations. On the 1st of April, the atmosphere of Pallas suddenly cleared up, and the solid nucleus or disc of the planet was alone visible. About 24 hours afterwards she appeared pale and surrounded with fog, and this appearance continued during the 3d and 4th of April. Schroeter has shewn, that this phenomenon does not arise from the diurnal rotation of the planet.

The diameter of Pallas has not yet been determined with sufficient accuracy. Dr. Herschel makes it only 80 miles, which is but one-half the diameter of Ceres, while Schroeter makes it no less than 2099 miles, which is considerably larger than the magnitude that he assigned to Ceres. The elements of the

orbit of Pallas, and the other particulars which are known respecting this planet are given in the following Table:—

	Years.	Months.	Days.
Tropical revolution,	4	7	11
Sydereal revolution, from Maskelyne's table,	1703d	16h	48′
Annual motion,	2°	18′	11″
Mean longitude, January 1, 1803,	221°	34′	53″.64
Place of ascending node in 1803,	172°	28′	12″.48
Place of perihelion,	121°	8′	8″.54
Eccentricity, the mean distance being 1,	0.2447424		
Inclination of orbit in 1803,	24°	37′	28″.35
Mean distance from the Sun, that of the Earth being 1,	2.768		
Mean distance in English miles,	266,000,000		
Diameter in English miles, according to Herschel,	80		
Ditto ditto according to Schroeter,	2099		
Ditto ditto, comprehending the atmosphere,	3036		
Height of Pallas' atmosphere,	468		
Apparent mean diameter, as seen from the Earth, according to Herschel,	0″.5		
Ditto according to Schroeter, comprehending the atmosphere at the mean distance of the planet from the Earth,	6″.514		

On Juno.

The planet Juno, situated between the orbits of Mars and Jupiter, was discovered by Mr. Harding, at the observatory of Lilienthal, near Bremen, on the evening of the 1st September 1804. While this astronomer was forming an atlas of all the stars, so far as the eighth magnitude, which are near the orbits of Ceres and Pallas, he observed, in the constellation Pisces, a small star of the eighth magnitude, which was not mentioned in the *Histoire Céleste* of La Lande; and being ignorant of its longitude and latitude, he put it down in his chart as nearly as he could estimate with his eye. Two days afterwards, the star disappeared; but he perceived another which he had not seen before, resembling the first in size and colour, and situated a little to the south-west of its place. He observed it again on the 5th of September, and finding that it had moved a little farther to the south-west, he concluded that this star belonged to the planetary system.

'The planet Juno is of a reddish colour, and is free from that nebulosity which surrounds Pallas. Its diameter and its mean distance are less than those of the other new planets. It is distinguished from all the other planets by the great eccentricity of its orbit; and the effect of this is so extremely sensible, that it passes over that half of its orbit which is bisected by its perihelion, in half the time that it employs in describing the other half, which is farther from the Sun From the same cause, its greatest distance from the Sun is double the least distance, the difference between the two distances being about 127 millions of miles.

Though there is no nebulous appearance around the planet Juno, yet it appears from the observations of Schroeter, that it must have an atmosphere more dense than that of any of the old planets of the system. A very remarkable variation in the brilliancy of this planet has been observed by this astronomer. He attributes it chiefly to changes that are going on in its atmosphere, though he thinks it not improbable that these changes may arise from a diurnal rotation performed in 27 hours. The following elements were calculated by Nicolai.

	Years. Days.
Annual revolution,	4 128
Mean longitude, 1819, at Manheim,	117° 45′ 2″.84
Place of ascending node,	171° 6′ 50″.23
Place of perihelion in 1819,	53° 32′ 56″.09
Eccentricity, Gauss,	0.2543634
Inclination of orbit,	13° 3′ 37″.29
Mean distance from the Sun in English miles,	280,000,000
Mean distance,	2.669
Daily tropical motion,	813″.86981
Diameter in English miles, according to Schroeter,	1425
Apparent mean diameter, as seen from the Earth, according to Schroeter,	3″.057

On Vesta.

From the regularity observed in the distances of the old planets from the Sun, some astronomers supposed that a planet existed between the orbits of Jupiter and Mars.[4] The dis-

[4] This idea was entertained by MM. Lambert, Bode, and Wurm. By assuming 10 as the mean distance of the Earth from the Sun, they found the follow-

covery of Ceres confirmed this happy conjecture; but the opinion which it seemed to establish respecting the harmony of the solar system, appeared to be completely overturned by the discovery of Pallas and Juno. Dr. Olbers, however, imagined that these small celestial bodies were merely the fragments of a larger planet, which had been burst asunder by some internal convulsion, and that several more might yet be discovered between the orbits of Mars and Jupiter. He therefore concluded, that though the orbits of all these fragments might be differently inclined to the ecliptic, yet, as they must have all diverged from the same point, they ought to have two common points of reunion, or two nodes in opposite regions of the heavens, through which all the planetary fragments must sooner or later pass. One of these nodes Dr. Olbers found to be in Virgo, and the other in the Whale, and it was actually in the latter of these regions that Mr. Harding discovered the planet Juno. With the intention, therefore, of detecting other fragments of the supposed planet, Dr. Olbers examined thrice every year all the little stars in the opposite constellations of the Virgin and the Whale, till his labours were crowned with success on the 29th March 1807, by the discovery of a new planet in the constellation Virgo, to which he gave the name of Vesta.

As soon as this discovery was made known in England, the planet was observed at Blackheath, on the 26th April 1807, by

ing remarkable law in the first differences of the distances of the other planets, in round numbers:—

	Distances.		
Mercury,	4	—	4
Venus,	7	=	$4 + 3.2^0$
Earth,	10	=	$4 + 3.2^1$
Mars,	16	=	$4 + 3.2^2$
Ceres,	28	=	$4 + 3.2^3$
Jupiter,	52	=	$4 + 3.2^4$
Saturn,	100	=	$4 + 3.2^5$
Uranus,	196	=	$4 + 3.2^6$
The distances of more remote Planets, if they exist,	388	=	$4 + 3.2^7$
	772	=	$4 + 3.2^8$
	1540	=	$4 + 3.2^9$
	3076	=	$4 + 3.2^{10}$

If we begin to reckon from Venus, and call n the rank of the planet, its distance will be $4 + 3.2^{n-2}$. This table may be prolonged by doubling the distance, beginning from the Earth, and subtracting 4. Thus for Uranus, we have $2 \times 100 - 4 = 196$. This law, which is quite empirical, is not rigorously accurate, and no conjecture has yet been formed respecting the foundation of it. See De Lambre's *Astronomie*, tom. ii, p. 549, 550.

S. Groombridge, Esq. an ingenious and active astronomer, who has successfully devoted his leisure and his fortune to the advancement of astronomy. He continued to observe it with his excellent astronomical circle till the 20th May, when, from its having ceased to become visible on the meridian, he had recourse to equatorial instruments. On the 11th of August, Mr. Groombridge resumed his meridional observation, from which he has computed part of the elements of its orbit; and he had the good fortune to observe the ecliptic opposition of the planet on the 8th of September 1808, at 7h 30′, in longitude 11s 15° 54′ 26″. His observations were continued till the beginning of November 1808, and he expected to have found the planet again at its opposition in February 1810; but, from a continuance of cloudy weather, and probably from errors in the elements, he did not succeed.

The planet Vesta is of the 5th or 6th magnitude, and may be seen in a clear evening by the naked eye. Its light is more intense, pure, and white than any of the other three; and it is very similar in its appearance to the Georgium Sidus. It is not surrounded with any nebulosity; and even with a power of 636, Dr. Herschel could not perceive its real disc. The orbit of Vesta cuts the orbit of Pallas, but not in the same place where it is cut by that of Ceres. According to the observations of Schroeter, the apparent diameter of Vesta is only 0.488 of a second, one half of what he found to be the apparent diameter of the 4th satellite of Saturn; and yet it is very remarkable, that its light is so intense, that Schroeter saw it several times with his naked eye.

M. Burckhardt is of opinion, that Le Monnier had observed this planet as a fixed star, since a small star, situated in the same place, and noticed by that astronomer, has since disappeared.

The following are the elements of the orbit of Vesta, computed by Mr. Groombridge, from his own observations.

	Years.	Days.	Hours.
Revolution,	3	66	4
Place of perihelion,	8s	13°	04′ 0″
Place of ascending node,	3s	14°	38′ 0″
Inclination of orbit,		7°	8′ 20″
Mean distance,			2.163
Eccentricity in parts of the Earth's radius,			0.0953

The following elements are given by M. Gauss:—

Mean longitude at Gottingen,	204° 48′ 45″
Place of ascending node,	103° 10′ 41″
Place of perihelion,	250° 19′ 36″
Inclination of orbit,	7° 7′ 51″
Mean distance,	2.363198
Eccentricity,	0.183826

The orbits of the four new planets projected from the places of their perihelion, and their eccentricities, as given in the preceding elements, are represented in the view of the solar system given in Plate I, and in Plate IV, Fig. 1. The mean distances employed are,

Ceres,	2.765
Pallas,	2.791
Juno,	2.657
Vesta,	2.373

The orbits appear to intersect each other in various places; and it is obvious, that the points of intersection must be perpetually shifting, according to the changes in the aphelia of the planets.

For farther information respecting the four new planets, see Herschel, *Phil Trans.* 1802, p. 213. Schroeter, *Lilienthalische Beobachtungen der neu entdecken planeten Ceres, Pallas, und Juno*, Gottingen, 1805. Schroeter, *Phil. Trans.* 1807, Part ii, p. 245. La Lande, *Journal de Physique*, Brum. An. 12. *Connoissance de Tems*, 1809. Groombridge, *Phil. Mag.* vol. xxvii, p 281.; vol. xxxi, p. 228. *Id.* p. 321.

CHAP. II.

ON THE ORIGIN OF THE FOUR NEW PLANETS, AND ON METEORIC STONES.

Origin of the four new planets.

THE existence of four planets between the orbits of Mars and Jupiter, revolving round the Sun at nearly the same distances, and differing from all the other planets in their diminutive size, and in the form and position of their orbits, is one of the most singular phenomena in the history of astronomy. The incompatibility of these phenomena with the regularity of the planetary distances, and with the general harmony of the system, naturally suggests the opi-

nion that the irregularities in this part of the system were produced by some great convulsion, and that the four planets are the fragments of a large celestial body which once existed between Mars and Jupiter. If we suppose these bodies to be independent planets, as they must be if they did not originally form one, their diminutive size, the great eccentricity and inclination of their orbits, and their numerous intersections when projected on the plane of the ecliptic, are phenomena absolutely inexplicable on every principle of science, and completely subversive of that harmony and order which before the discovery of these bodies pervaded the planetary system. But if we admit the hypothesis, that these planets are the remains of a larger body, which circulated round the Sun nearly in the orbit of the greatest fragment, the system resumes its order, and we discover a regular progression in the distances of the planets, and a general harmony in the form and position of their orbits. To a mind capable of feeling the force of analogy, this argument must have no small degree of weight, and might be reckoned a sufficient foundation for a philosophical theory. We are fortunately, however, not left to the guidance merely of analogical reasoning. The elements of the new planets furnish us with several direct arguments drawn from the eccentricity and inclination of their orbits, and from the position of their perihelion and nodes, and all concurring to shew that the four new planets have diverged from one point of space, and have therefore been originally combined in a larger body.

To those who are acquainted with physical astronomy, it is needless to state the difficulty of ascertaining the paths of four bodies whose masses are known, and which have diverged from one common node, with velocities given in quantity and direction. This problem is much more perplexing than the celebrated problem of three bodies, and is therefore beyond the grasp of the most refined analysis. It is not difficult, however, to ascertain, in general, the consequences that would arise from the bursting of a planet, and to determine within certain limits the form and position of the orbits, in which the larger fragments would revolve round the Sun.

When the planet is burst in pieces by some internal force capable of overcoming the mutual attraction of the fragments, it is obvious that the larger fragment will receive the least impetus from the explosive force, and will therefore circulate in an orbit

deviating less than any other of the fragments from the original path of the large planet; while the lesser fragments being thrown off with greater velocity, will revolve in orbits more eccentric, and more inclined to the ecliptic. Now the eccentricity of Ceres and Vesta is nearly $\frac{1}{12}$ of their mean distance, that of Ceres being rather the greatest; and the eccentricity of Pallas and Juno is $\frac{1}{4}$ of their mean distance, the eccentricity of Pallas being a little greater than that of Juno. We should therefore expect from the theory, that Pallas and Juno would be considerably smaller than Ceres and Vesta, and that Ceres should be the larger fragment, and should have an orbit more analogous in eccentricity and inclination than that of any of the smaller fragments to the other planets of the system. In so far as the diameters of the new planets have been measured, the theory is most strikingly confirmed by observation. According to Dr. Herschel, the diameter of Ceres is 163 miles, while that of Pallas is only 80. The observations of Schroeter make Juno considerably less than Ceres: and though the diameter of Vesta has not been accurately ascertained, yet the intensity of its light, and the circumstance of its being distinctly visible to the naked eye, are strong proofs that it exceeds in magnitude both Pallas and Juno. The striking resemblance between the two lesser fragments Pallas and Juno in their magnitudes, and in the extreme eccentricity of their orbits, would lead us to anticipate similar resemblances in the position of their nodes, in the place of their aphelia, and in the inclination of their orbits; while the elements of Ceres and Vesta should exhibit similar coincidences. Now the inclination of Ceres is 10°, and that of Vesta 7°; while the inclination of Juno is 21°, and that of Pallas $24\frac{1}{2}$°; the two greater fragments having nearly the same inclination, and keeping near the ecliptic, while the lesser fragments diverge from the original path, and rise to a great height above the ecliptic, and far above the orbits of all the other planets in the system. The inclination of the orbits of all the new planets is represented in Plate V, Fig. 24, where the greatest angle of divergency is $17\frac{1}{2}$°. If it shall be found, from observation, that Vesta is one of the smaller fragments, we may then account for its position with regard to Ceres, and for the small inclination and eccentricity of its orbit, by supposing the planets Ceres, Pallas, and Juno, to have diverged in the same plane, and nearly at right angles to the ecliptic, while Vesta diverged

from the direction of the original planet in a plane parallel with the ecliptic. This will be understood from Fig 25, where *O C* is the path of the greater fragment Ceres; *O J*, *O P*, the direction in which the fragments Juno and Pallas were projected, lying in different planes *O C J*, *O C P*; and *O V*, the direction in which Vesta was projected in a plane *O C V*, nearly perpendicular to the plane *O P C*. This opinion is strongly confirmed by the fact, that the orbit of Vesta is nearer to the Sun than any of the orbits of the other three fragments.

In the position of the nodes, we perceive the same coincidence. The orbits of Pallas and Juno cut the ecliptic in the same point, and the nodes of Ceres and Vesta are not far distant. This will be distinctly seen in Fig. 26, where the two smaller fragments still keep together, and the two larger ones are not very remote.

If all the fragments of the original planet had, after the explosion, been attracted to the larger fragment, it is obvious that they would all move in the same orbit, and consequently have the same perihelion. If the fragments received a slight degree of divergency from the explosive force, and moved in separate orbits, the points of their perihelion would not coincide, and their separation would increase with the divergency of the fragments. But since all the fragments partook of the motion of the primitive planet, the angle of divergency could never be very great, and therefore we should expect that all the perihelia of the new planets would be in the same quarter of the heavens. This theoretical deduction is most wonderfully confirmed by observation. It will appear from Fig. 27, where we have projected the perihelia of the four new planets, that all the perihelia are in the same semicircle, and all the aphelia in the opposite semicircle; the perihelia of the two larger fragments, Ceres and Vesta, being near each other, as might have been expected, while there is the same proximity between the perihelia of the lesser fragments Pallas and Juno.

These singular resemblances in the motions of the greater fragments, and in those of the lesser fragments, and the striking coincidence between theory and observation in the eccentricity of their orbits, in their inclination to the ecliptic, in the position of their nodes, and in the places of their perihelia, are phenomena which could not possibly result from chance, and which concur to prove, with an evidence amounting almost to

demonstration, that the four new planets have diverged from one common node, and have therefore composed a single planet.

On the origin of meteoric stones.

Let us now proceed to consider the other phenomena which might be supposed to accompany this great convulsion. When the cohesion of the planet was overcome by the action of the explosive force, a number of little fragments, detached along with the greater masses, would, on account of their smallness, be projected with very great velocity; and being thrown beyond the attraction of the larger fragments, might fall towards the Earth when Mars happened to be in the remote part of his orbit. The central parts of the original planet being kept in a state of high compression by the superincumbent weight, and this compressing force being removed by the destruction of the body, a number of less fragments might be detached from the larger masses by a force similar to the first. These fragments will evidently be thrown off with the greatest velocity, and will always be separated from those parts which formed the central portions of the primitive planets. The detached fragments, therefore, which are projected beyond the attraction of the larger masses, must always have been torn from the central parts of the original body; and it is capable of demonstration, that the superficial or stratified parts of the planet could never be projected from the fragments which they accompany.

When the portions which are thus detached arrive within the sphere of the Earth's attraction, they may revolve round that body at different distances, and may fall upon its surface in consequence of a diminution of their centrifugal force; or, being struck by the electric fluid, they may be precipitated on the Earth, and exhibit all those phenomena which usually accompany the descent of meteoric stones. Hence we perceive the reason why the fall of these bodies is sometimes attended with explosions, and sometimes not; and why they generally fall obliquely, and sometimes horizontally, a direction which they never could assume if they descended from a state of rest in the atmosphere, or had been projected from volcanoes on the surface of the Earth.

If we compare the specific gravity of meteoric stones with the density of the new planets, we shall obtain another argument in support of the theory. It appears from the observations of Dr.

Maskelyne on the attraction of Shehallien, and particularly from the experiments of Mr. Cavendish on the attraction of leaden balls, that the density of the Earth increases towards its centre; and therefore the density of the central parts must exceed the average density of the whole globe. This gradation of density no doubt arises from the weight of the superincumbent mass; and hence we are fully entitled to conclude, that the density of the central parts of every other planet is greater than the average density of the body. As it is demonstrable, therefore, that the fragments of the large planet, which are supposed to be meteoric stones, must have been detached from the central parts of the primitive planet, the specific gravity of meteoric stones ought to exceed the average density of the planet. According to the observations of Mr. Playfair, the density of Shehallien i only 2.7, while that of the Earth is 4.8; so that the density of the central parts of our globe cannot be less than 7 or 8, in order to make up the mean density. Now, the density of the new planets, estimated from their position in the system by the method of Lagrange, is nearly 2; and reasoning from analogy, and following the proportion already stated in the case of the Earth, we should expect that the average density of meteoric stones should be about 3.2, which happens to be the exact specific gravity of the greatest number of these bodies. This coincidence is truly surprising, and when taken in connection with the evidence arising from the form and position of the orbits of the new planets, gives a probability to the theory which no other hypothesis can claim. Those who maintain that meteoric stones have fallen from the Moon, or have been produced in our own atmosphere, have adopted these hypotheses because they had no other to choose. To suppose that dense bodies, containing a great proportion of iron, are generated in the air, is an assumption repugnant to every principle of science; and to maintain that they are projected by lunar volcanoes, when such volcanoes are only conjectured to exist, and when a force of projection would be requisite, which has never been exhibited in any volcanic eruption on our earth, is one of those hypotheses which is neither suggested by facts, nor founded on analogy. Astronomers have indeed perceived some faint gleams of light in the obscure part of the lunar disc, but this is no proof that these radiations are the flames of a volcano. The aeronaut, who is hovering above our own globe, might, with equal

justice, imagine, that he was soaring above burning mountains, when he saw merely an accidental fire, or was contemplating tracts of heath that were occasionally blazing upon its surface.

We shall now conclude this section, by endeavouring to answer a very plausible objection which may be urged against the preceding theory. If meteoric stones are the fragments of a planet, why are they all of the same kind? If our own Earth were to be burst in pieces, we should find among its fragments stones of every description. This objection is founded on the supposition that the Earth is everywhere stratified, and that there exists at its centre the same diversity of minerals which occur at its surface. This opinion is purely hypothetical. We have scarcely penetrated beyond the surface of the globe, and we have every reason to believe that the stratification is completely superficial. The density of the internal mass is known to be extremely great, and the magnetism of the Earth demonstrates that this mass must be either iron-stone or melted metals which have the magnetic virtue. Now, if we suppose the Earth to be burst in pieces by some internal force, the smaller fragments that would be projected beyond its sphere of attraction must come from the central parts, and none of the superficial or stratified parts would be detached from the fragment to which they belong. The only way in which we can conceive the superficial parts of the planet to be affected, is by the shock given to the fragment on which they rest. But this shock cannot possibly produce a velocity greater than the velocity of the fragment itself; and since the fragment is supposed by the hypothesis to continue in an orbit not far from the orbit of the original planet, its superficial parts must also remain in the same region of the heavens. The portions of our globe, therefore, that would be thrown beyond the reach of its attraction, would be the dense parts towards its centre, which in all probability would be either iron-stone, or melted metals that had the magnetic virtue. Reasoning from analogy, therefore, we should draw the same conclusion respecting the imaginary planet between Mars and Jupiter; and it is a very singular circumstance, that meteoric stones contain a great porportion of iron, that they are endowed with the magnetic virtue, and that the large meteoric stones which have been found in Siberia and in South America are masses of melted iron.

It would not be difficult to anticipate a number of objections

which might be urged against the preceding theory; but however formidable these may be, we ought to remember, that such difficulties do not belong to the hypothesis itself, but arise from our ignorance of the changes induced upon the fragments during their passage through the Earth's atmosphere; and that they belong equally to every hypothesis that has yet been suggested. It is not fair, therefore, to demand from one theory an explanation of difficulties which belong to all. It is sufficient to give a plausible explanation of the phenomena; and to combine, under a general principle, the scattered facts that cannot otherwise be generalised consistently with the established laws and analogies of nature.

Since the preceding views were laid before the public, the celebrated M. De Lagrange has published a memoir on planetary explosion, in the *Connoissance des Tems* for 1814, p. 211. He supposes the bursting of a planet to be a very probable event, and he has investigated formulæ for computing the velocity with which the fragments of a burst planet must be projected, in order to move in elliptical, parabolic, or hyperbolic orbits. He determines also the explosive force necessary to burst a planet, so that one of its fragments may become a comet, and he shews that a fragment detached from the Earth would become a direct comet if the velocity of its projection were 121 times that of a cannon-ball, and a retrograde comet, if its velocity were 196 times that of a cannon-ball. For planets situated beyond the orbit of the Georgium Sidus, a velocity 12 or 15 times greater than that of a cannon-ball would make the fragments move in an elliptical or parabolic orbit, whatever be the dimensions of the direction in which they are projected. In the case of other planets than the Earth, the number of times the velocity of a cannon-ball that the fragment should have to become a comet will be found by dividing 121 or 156, according as it is to be direct or retrograde, by the square root of the mean distance of the planet. As a less velocity is requisite to make the fragments move in an ellipse, the velocity necessary for the four small planets will be less than 20 times that of a cannon-ball.

CHAP. III.

ON THE NEW DISCOVERIES, &c. IN MERCURY, VENUS, MARS, JUPITER, AND SATURN.

However brilliant have been the discoveries in astronomy, by which the present century has been distinguished, yet those which were made on the old planets of the system by Dr. Herschel and Mr. Schroeter, with the assistance of powerful telescopes, are not less interesting and important. The discovery of mountains in Mercury and Venus, of the double ring and interior satellites of Saturn, and the determination of its diurnal revolution, are a few of the important facts which have been added to astronomy, by the improvement of the telescope.

On Mercury.

The planet Mercury is about 3224 English miles in diameter, and revolves round the Sun at the distance of 37 millions of miles. He emits a brilliant white light, and twinkles like the fixed stars. The dazzling splendour of his rays, the shortness of the interval during which observations can be made upon his disc, and his proximity to the vapours of the horizon when he is observed, have prevented astronomers from making any interesting discoveries respecting this planet. When Mercury is viewed with a telescope of high magnifying power, he exhibits to all the other planets nearly the same phases, as the Moon does to the Earth, being sometimes horned, and sometimes nearly full. Dr. Herschel has frequently examined Mercury with telescopes magnifying 200 and 300 times; but he always appeared equally luminous in every part of his disc, without any dark spot or ragged edge. Mr. Schroeter, however, would appear to have been more successful. He maintains that he has seen not only spots, but even mountains, in Mercury; and that he succeeded in measuring the altitude of two of them. One of these mountains was little more than 1000 toises in height, but the other measured 8900 toises, or ten miles and three quarters, which is nearly thrice as high as

Chimboraco, the highest mountain upon our own Earth. The highest mountains are situated in the southern hemisphere of Mercury. By examining the variation in the daily appearance of Mercury's horns, Schrbeter found the period of his diurnal rotation about his axis to be 24 days 5 hours and 28 minutes. Wallot imagined that Mercury had a horizontal refraction of 276″; but Bugge, when observing the transit of this planet in 1802, could perceive no traces of an atmosphere.

Venus

We have already given some account of the observations by which Cassini and Bianchini endeavoured to ascertain the diurnal revolution of Venus. Figures 1st and 2d of Plate II, *Sup.* represent the spots observed by Bianchini. Plate II. Fig. 1. and 2.

The powerful telescopes of Dr. Herschel and Mr. Schroeter have been recently employed in examining the various appearances of this planet. On the 19th June, 1780, Dr. Herschel observed spots upon the surface of this planet, as represented in Figure 3d, where *a d c* is a bluish darkish spot, and *c e b* a brighter spot. They met in an angle at a point *c*, about one-third of the diameter of Venus from the cusp *a*. This astronomer also observed, that Venus was much brighter round her limb, than in that part which separates the enlightened from the obscure part of her disc. As this brightness round her limb diminishes pretty suddenly, it resembles a narrow luminous border, and therefore does not seem to be the result of any optical deception. The light seemed to decrease gradually between this border and the boundary between the illuminated and obscure parts of her disc. Mr. Schroeter had observed before Dr. Herschel, "that the light appears strongest at the outward limb, from whence it decreases gradually, and in a regular progression towards the interior edge;" but he differs from the doctor with regard to the sudden diminution of this marginal light. "With regard to the cause of this appearance," says Dr. Herschel, "I may venture to ascribe it to the atmosphere of Venus, which, like our own, is probably replete with matter that reflects and refracts light copiously in all directions. Therefore, on the border where we have an ob-

Spots of Venus. Plate II. Fig. 3, *Sup.*

Atmosphere of Venus.

lique view of it, there will, of consequence, be an increase of this luminous appearance." Dr. Herschel considers the real surface of Venus to be less luminous than her atmosphere, and this accounts for the small number of spots which appear upon her disc. "For this planet," says he, "having a dense atmosphere, its real surface will commonly be enveloped by it, so as not to present us with any variety of appearances. This also points out the reason why the spots, when any such there are, appear generally of a darker colour than the rest of the body." The observations of this astronomer did not enable him to ascertain the diurnal rotation of Venus, or the position of her axis; but he is of opinion, that it can hardly be so slow as 24 days, the period assigned by Bianchini.

The atmosphere of Venus appears to be very dense, not merely from the changes which take place in her dark spots, but as Schroeter inferred, from the illumination of her cusps when she is near her inferior conjunction, where the enlightened ends of the horns reach far beyond a semicircle.

Mr. Schroeter seems to have been very successful in his observations upon Venus; but the results which he has obtained are more different than could have been wished from the observations of Dr. Herschel. He discovered several mountains in this planet, and found, that like those of the Moon, they were always highest in the southern hemisphere, their perpendicular heights being nearly as the diameters of their respective planets. From the 11th December 1789, to the 11th of January 1790, the southern horn b of Venus appeared much blunted, with an enlightened mountain m, in the dark hemisphere, about 18300 toises, or nearly 22 miles high.

Plate II. Fig. 6.

Height of the mountains in Venus.

Mr. Schroeter measured the altitude of four mountains in Venus, and obtained the following results:—

	Toises.	Miles.		Toises.	Miles.
Highest,	18900	22.05	3d Highest,	9500	11.44
2d Highest,	15750	18.97	4th Highest,	9000	10.84

In order to determine the daily period of the planet, Mr. Schroeter observed the different shapes of the two horns of Venus. Their appearance generally varied in a few hours, and

became nearly the same at the corresponding time of the subsequent day, or rather about half an hour sooner every day. Hence he concluded, that the period must be about $23\frac{1}{3}$ hours; that her equator is considerably inclined to the ecliptic, and the pole at a considerable distance from the point of the horn. On the 30th of December 1791, at 8 o'clock in the morning, the southern horn appeared with the same bluntness, and with the same enlightened mountain in the dark hemisphere, that it had done on the 28th December 1789, at 5 o'clock in the morning. Hence he found, that the period of Venus's daily motion about her axis, must be $23^h\ 20'\ 59''$, only about one minute less than that which is given by Cassini. This alternate bluntness and sharpness in the horns of Venus, Schroeter supposes to arise from the shadow of a high mountain. The appearance of Venus, with her rugged edge and blunt horn, is represented in Fig. 4, 5.

Daily period of Venus.

Plate II. Figs. 4, 5.

The luminous margin which we have already mentioned, induced Mr. Schroeter to believe, that this planet had an atmosphere of a considerable extent. At the interior edge the light becomes dim, till it loses itself in a faint bluish grey, forming a ragged margin (as in Fig. 4, 5), which it is difficult to perceive even with the best telescopes. This diminution of light is much more sensible about the middle *d*, than at the cusps *a*, *b*.

Luminous margin of Venus.

On the 9th of September 1790, he observed, that the southern cusp of Venus disappeared, and was bent like a hook, about 8″ beyond the luminous semicircle, into the dark hemisphere. The northern cusp had the same tapering termination, but did not encroach upon the dark part of the disc. A streak, however, of the glimmering bluish light proceeded about 8″ along the dark limb, from the point of the cusp from *b* to *c* (Fig. 4, 5), *b* being the extremity of the diameter *a b*, and consequently the natural termination of the cusp. The streak *b c*, verging to a pale grey, was faint when compared with the light of the cusp at *b*. This phenomenon Mr. Schroeter considers as the twilight, or crepuscular light of Venus. "That it is a real twilight," says he, "will appear from the relative appearances of the cusps. On the 9th and 12th March 1790, when the southern cusp extended in a hooked direction, into the dark hemisphere, the pale blue light

Atmosphere and twilight in Venus.

appeared only at the point of the northern cusp, and proceeded in a spherical curve into the dark part. On the 10th of March, when the southern cusp did not proceed so far, the pale streak was perceived at both points, but more sensibly at the northern. The bright prolongation of the southern cusp on the 10th and 12th of March, must be ascribed to the solar light on a ridge of mountains, whence it could not be strictly spherical. When the bright prolongation was not considerable, twilight had its due effect, and the true spherical arc of the dark limb appeared faintly illuminated." From these observations, Mr. Schroeter has calculated that the dense part of Venus's atmosphere is about 16.020 feet high; and he concludes, that it must rise far above the highest mountains, that it is more opaque than that of the Moon, and that its density is a sufficient reason why we do not discover, in the surface of Venus, those superficial shades and varieties of appearance, which are to be seen on the other planets.

Venus larger than the Earth.

The planet Venus has generally been considered as about 220 miles less in diameter than the Earth, but it appears from the measurements of Dr Herschel, that when reduced to the mean distance of the Earth, her apparent mean diameter is 18".79, that of the Earth being 17".2, that is, 8648 English miles, that of the Earth being 7912. This result is rather surprising, but the observations have the appearance of accuracy.

Method of finding her phases.

The explanation of the different phases of Venus has been already given in Vol. I. We shall therefore conclude this section with pointing out the method of finding the proportion between the illuminated and obscure part of her disc at any given time. The following table, calculated for this purpose by Mr. Bode of Berlin (See *Tables de Berlin*, vol. iii, p. 257), answers for finding the phases of the Moon, as well as those of Venus.

Table.—To find the enlightened Part of the Diameter of the Moon or Venus, supposing the Diameter to be divided into 12 equal Parts.

Degrees.	For the Moon.—Argument. Distance of the Moon from the Sun.						
	Signs 0	Signs I.	Signs II.	Signs III.	Signs IV.	Signs V.	
	For Venus.—Argument. Angle formed at the centre of Venus, by two lines drawn from Venus to the Sun and Earth.						
	0°	30°	60°	90°	120°	150°	
	Parts.	Parts.	Parts.	Parts.	Parts.	Parts.	
0	0.000	0.804	3.000	6.000	9.000	11.196	30
1	0.001	0.857	3.092	6.101	9.090	11.247	29
2	0.004	0.912	3.184	6.209	9.179	11.297	28
3	0.009	0.969	3.277	6.314	9.267	11.346	27
4	0.015	1.026	3.370	6.418	9.355	11.392	26
5	0.023	1.085	3.465	6.523	9.441	11.437	25
6	0.033	1.146	3.560	6.627	9.526	11.481	24
7	0.045	1.209	3.656	6.731	9.611	11.523	23
8	0.059	1.272	3.753	6.834	9.694	11.563	22
9	0.074	1.337	3.850	6.938	9.776	11.601	21
10	0.091	1.401	3.918	7.041	9.856	11.638	20
11	0.110	1.472	4.047	7.145	9.936	11.673	19
12	0.131	1.542	4.147	7.217	10.014	11.706	18
13	0.154	1.612	4.247	7.349	10.091	11.737	17
14	0.179	1.684	4.317	7.451	10.167	11.767	16
15	0.205	1.758	4.448	7.552	10.212	11.795	15
16	0.233	1.833	4.549	7.653	10.316	11.821	14
17	0.263	1.909	4.651	7.753	10.388	11.846	13
18	0.294	1.986	4.753	7.853	10.458	11.869	12
19	0.327	2.064	4.855	7.953	10.528	11.890	11
20	0.362	2.144	4.959	8.052	10.596	11.909	10
21	0.399	2.224	5.062	8.150	10.663	11.926	9
22	0.437	2.306	5.166	8.247	10.728	11.941	8
23	0.477	2.389	5.269	8.344	10.791	11.955	7
24	0.519	2.474	5.373	8.440	10.854	11.967	6
25	0.563	2.559	5.477	8.535	10.915	11.977	5
26	0.608	2.645	5.582	8.630	10.974	11.985	4
27	0.654	2.733	5.686	8.723	11.031	11.991	3
28	0.703	2.821	5.791	8.816	11.088	11.996	2
29	0.753	2.910	5.896	8.908	11.143	11.999	1
30	0.804	3.000	6.000	9.000	11.196	12.000	0
	150°	120°	90°	60°	30°	0°	Degrees.
	For Venus.—Argument. Angle formed at the centre of Venus, by two lines drawn from Venus to the Sun and Earth.						
	Signs XI.	Signs X.	Signs IX.	Signs VIII.	Signs VII.	Signs VI.	
	For the Moon.—Argument. Distance of the Moon from the Sun.						

The argument of the preceding table, when applied to Venus, is the angle formed at her centre, by two lines drawn from Venus to the Sun and to the Earth. In order to find this angle, suppose that another line is drawn joining the Earth and Sun. Then add the angle formed at the Sun, or the anomaly of commutation, to the difference between the geocentric longitudes of the Sun and Venus, and this sum being subtracted from six signs, or 180 degrees, will leave the angle formed at Venus.

Explanation of the Table.

Example.

Let it be required, for example, to find the proportion between the enlightened and the dark portion of Venus's disc, on the 2d of August 1809. The Sun's longitude being then, 4ˢ 9° 41′; the heliocentric longitude of Venus 11ˢ 23° 49′; and her geocentric longitude 2ˢ 24° 2′, as found from the nautical almanack. Then, as the anomaly of commutation is equal to the difference between the heliocentric longitude of the planet and the longitude of the Earth, as seen from the Sun, we have

Helioc. long. of Venus,	11ˢ 23° 49′
Long. of Earth, subtract	10ˢ 9° 41′
Angle at the Sun, or anomaly of commutation,	1ˢ 14° 8′
Long. of Sun,	4ˢ 9° 41′
Geoc. long. of Venus, subtract	2ˢ 24° 2′
Difference between geoc. long. of the Sun and Venus,	1ˢ 15° 39′
Angle at the Sun, add	1ˢ 14° 8′
Sum subtract,	2ˢ 29° 47′
From six signs,	6ˢ 0° 0′
Argument,	3ˢ 0° 13′
or	90° 13′

With this argument enter the table, and you will find 6.000 answering to 90, and the proportional parts for 13′, found by the rule of proportion, will be .023, which, subtracted from 6.000, as the numbers in the table are decreasing, leaves 5.977 for the diameter of the enlightened part of Venus. Her whole diameter being 12.000, the diameter of the dark part of her disc will be 6.023; so that she is nearly a half Moon, and not far from her greatest elongation from the Sun.

The planet Venus may be often seen in the day-time with the naked eye; and by means of a telescope, furnished with a screen

for intercepting the direct rays of the Sun, she may be observed when she is very near the Sun, both at the superior and inferior conjunctions.

Mr. Dick of Perth has been particularly successful in seeing Venus under these circumstances. He observed her on the 16th October 1819, when she was only 6 *days and* 19 *hours* past her superior conjunction. At that time her distance from the Sun's eastern limb was only 1° 28′ 42″. Hence Mr. Dick concludes, 1*st*, That Venus may be distinctly seen at the moment of her superior conjunction with the Sun, with a moderate magnifying power, when her geocentric latitude exceeds 1° 44′ 47″; and, 2*dly*, That during the space of 583 days, in all 19 months, the time of her revolving from one conjunction of the Sun to a like conjunction again, when the latitude, at the time of her superior conjunction exceeds 1° 44′ 47″, *she may be seen by means of an equatorial telescope every clear day without interruption, except at the moment of her inferior conjunction, and four days before and after it. See the Edinburgh Philosophical Journal*, vol. iii, p. 191.

Mars.

The planet Mars is remarkable for the redness of its light, the brightness of its polar regions, and the variety of spots which appear upon its surface. The atmosphere of this planet, which astronomers have long considered as of an extraordinary size and density, is the cause of the remarkable redness of its light. When a beam of white light passes through any medium, its colour inclines to red, in proportion to the density of the medium, and the space through which it has travelled. The momentum of the red, or least refrangible rays, being greater than that of the violet or most refrangible rays, the former will make their way through the resisting medium, while the latter are either reflected or absorbed. The colour of the beam, therefore, when it reaches the eye, must partake of the colour of the least refrangible rays, and this colour must increase with the number of the violet rays that have been obstructed. Hence we see that the morning and evening clouds are beautifully tinged with red; that the Sun, Moon, and stars, appear of the same colour when near

Cause of the red colour of Mars.

the horizon; and thate very luminous object seen through a dry mist is of a ruddy hue. Now, the planet Mars is allowed to have an atmosphere of great density and extent, as is manifest from the dim appearance of the fixed stars, that are placed even at a distance from his disc.[1] The dim light, therefore, by which Mars is illuminated, having to pass twice through his atmosphere before it reaches the Earth, must be deprived of a great proportion of its violet rays, and consequently the colour of the resulting light by which Mars is visible must be red. As there is a considerable difference of colour among the other planets, and likewise among the fixed stars, are we not entitled to conclude, that those in which the red colour predominates, are surrounded with the greatest, or densest atmospheres? According to this principle, the atmosphere of Saturn must be the next to that of Mars in density or extent.

After Galileo had discovered the phases of Mars, which are mentioned in Chap. II, p. 22, 23, Vol. i, Dr. Hook and Cassini discovered upon the disc of this planet a number of dark spots. Dr. Hook perceived some trifling changes in their position, but Cassini had the merit of determining from these changes, that the diurnal revolution of the planet was performed in 24 hours 40 minutes.

The luminous zone at the southern pole of Mars, which had been often noticed by astronomers, was particularly observed by Maraldi. During six months' observations, he found it subject to many changes. Sometimes it appeared bright, at other times faint, and after completely disappearing, it returned with its original brightness. When this spot was most luminous, the disc of Mars did not appear exactly round, but the bright part of its southern limb that terminated this spot appeared to project like a bright cap, whose exterior arch was a portion of a larger extent than the rest of the planet's limb. This appearance resembled exactly the new Moon, when the dark part of her disc is enlightened by the Earth, and is evidently an optical deception, arising from the same cause. See Chap V.

The luminous zone at the south pole of Mars.

[1] Cassini observed, that a star in Aquarius, at the distance of six minutes from the disc of Mars, became so faint before its occultation, that it could not be seen even with a three-foot telescope. The same phenomenon was observed by Roemer at Paris. Dr. Herschel considers the atmosphere of Mars as less than has been generally imagined, but he still regards it as dense and extensive.

In 1719, a favourable opportunity occurred for observing the spots upon Mars. When he was within two degrees of his perihelion, he was in opposition to the Sun, and appeared superior to Jupiter in brightness and magnitude. Maraldi observed him at that time through a refracting telescope 34 feet long, and saw the appearance which is represented in Figs. 1 and 2. A long belt extending half way round his disc, was joined by a shorter belt, forming with it an obtuse angle. By the motion of this angular point, Maraldi found its daily period to be 24^h 40′, the very same with that of Cassini.

Plate III. *Sup.* Fig. 1, 2.

Dr. Herschel's observations on Mars.

These luminous spots were observed from 1777 to 1783 by Dr. Herschel, who, by ascertaining the changes in their position, has determined the inclination of the axis, and the place of the nodes of Mars. The polar spots are represented at *a* in Figures 3, 4, 5, 6, 7, 8, 9, 10, 11, where *a* is the south polar spot, and *b* the north polar one. In Fig. 4, the south polar spot has a very singular appearance, similar to what was observed by Maraldi. In consequence of its great splendour, it seems to project beyond the disc of Mars, producing a break at *c*, increased by the gibbous appearance of the planet. The south polar spot is represented in Figures 5, 6, 7, 8, 9, 10, 11, which complete the whole equatorial circle of appearances in Mars, as they are observed in immediate succession. These Figures are all connected together in one projection, in Fig. 12. "The centre of the circle marked 17," says Dr. Herschel, "is placed on the circumference of the inner circle, by making its distance from the centre of the circle marked 15, answer to the interval of time between the two observations, properly calculated and reduced to sydereal measure. The same has been done with regard to the circles marked 18, 19, 20, &c. And it will be found by placing any of these connected circles, so as to have its contents in a similar situation with the figures in the single representation which bear the same number, that there is a sufficient resemblance between them; but some allowance must undoubtedly be made for the unavoidable distortions occasioned by this kind of projection. (*Phil. Trans.* 1784, p. 241.)

Fig. 12.

From the similarity between Mars and the Earth, in their diurnal motion, and in the position of their equator, Dr. Herschel imagines that the bright spots at the poles of this pla-

net are produced by the reflection of the Sun's light from its frozen regions, and that the melting of masses of polar ice is the cause of the variation in the magnitude of the spots. Hence, in 1781, when the Antarctic glaciers had not felt for twelve months the thawing influence of the Sun, the south polar spot was extremely large, and in 1783, it had suffered a considerable diminution from an exposure of 8 months to the solar rays.

As the diurnal rotation of Mars has been accurately established by the motion of its spots, it was natural to expect, that in conformity to the laws of gravity, it should exhibit a spheroidal form. Owing to the gibbous appearance of this planet, there is some difficulty in taking accurate measures of his equatorial and polar diameters. Dr. Herschel, however, has succeeded in the attempt, and found that the figure of Mars was an oblate spheroid, whose equatorial diameter is to the polar as 1355 to 1272, or nearly as 16 to 15. Dr. Herschel also found, that the inclination of Mars' axis to the ecliptic is 59° 42′; that the node of the axis is in 17° 47′ of Pisces; that the obliquity of the ecliptic on the globe of Mars, is 28° 42′; that the point Aries on the ecliptic of Mars, answers to our 19° 28′ of Sagittarius; that the equatorial diameter of Mars reduced to the mean distance of the Earth, is 9″ 8‴, and that the time of his diurnal rotation is 24^h 39′. The remarkable flattening at the poles of Mars probably arises from a considerable variation in the density of his different parts. La Place has computed the density of this planet to be about $\frac{3}{4}$ of that of the Earth.

From the circumstance of Mars's having no satellite, and appearing to require light in the Sun's absence, M. Fontenelle has imagined that this planet is phosphorescent, and gives out, during night, the light which it has imbibed in the day.

Jupiter.

Jupiter. The planet Jupiter revolves round his axis in 9 hours 55 minutes and 37 seconds. His form, like that of the Earth and Mars, is an oblate spheroid, the equatorial being to the polar diameter as 14 to 13. This result was obtained from the accurate observations of Dr. Herschel, and it is a remarkable coincidence between theory and observation, that from the influence of the equatorial parts of Jupiter upon

the motion of the nodes of his satellites, La Place has found the proportion between his equatorial and polar diameters to be as 10000000 to 9286992, a result which differs only a very little from the ratio of 14 to 13.

When we look at Jupiter through a good telescope, we perceive several belts or bands extending across his disc, in lines parallel to his equator. These appearances were first observed by two Jesuits, Zappi and Bartoli. They were afterwards examined in 1633, by Fontana, Rheita. Riccioli, Grimaldi, and Campani, the last of whom, on the 1st of July 1664, perceived four dark belts, and two white ones. These belts are variable both in number, distance, and position. Sometimes 7 or 8 belts have been observed, and on the 28th May 1780, Dr. Herschel perceived the whole disc of Jupiter covered with small curved belts, or rather lines, that were not continuous across his disc. This appearance of the planet is represented in Plate III, Fig. 13, 14. The parallel belts, however, are most common, and in clear weather may be seen by a good achromatic telescope, with a magnifying power of 40. The appearance which they exhibit in Dr Herschel's telescopes, is represented in Figures 15 and 16. Sometimes they are interrupted in their length, as in Fig. 15. At other times they seem to increase and diminish alternately, to run into one another, or to separate into others of a smaller size. Bright and dark spots frequently appear in the belts, as represented in Fig. 16. Some of these revolve with greater rapidity than others, from which it appears, that they are not permanent spots upon the planet itself.

Jupiter's belts.

Plate III. Fig. 13, 14.

Fig. 15, 16.

When Jupiter was in his perihelion in 1785 and 1786, M. Schroeter observed his belts with a four-foot Newtonian telescope, magnifying 150 times. He perceived upon his disc, several new spots, which were black and round. In 1787, he saw two dark belts in the middle of Jupiter's disc, and near to them, two white and luminous belts, resembling those which were observed by Campani The equatorial zone, which was comprehended between the two dark belts, had assumed a dark grey colour, bordering upon yellow. The northern dark belt then received a sudden increase of size, while the southern one became partly extinguished, and afterwards increased into an uninterrupted belt. The luminous belts also suffered several

changes, growing sometimes narrower, and sometimes one half larger than their original size.

The appearance of Jupiter, as seen by Schroeter at the time of its occultation by the Moon, on the 7th April 1792, is represented in Plate V, Fig. 5. The equatorial belt from *a* to *d* was very distinct, consisting of two zones *a b*, *c d*, of a brownish grey colour, separated by a more luminous interval *b c*. Two well defined stripes, which Schroeter had noticed for two years, appeared at *c* and *f*; and now crossed the whole disc. The polar regions at *g* and *h* appeared more dim and grey than the bright part of the planet. The most remarkable phenomena, however, were two nebulous undefined spots *i* and *k*, perceptibly darker than the principal belt *d d*; and a still more remarkable spot *l*, circular and imperfectly defined, and somewhat brighter than the luminous space *b c c b*. A similar spot was observed in 1786 and 1787 in the same part of the planet. At $10^h\ 40'\ 50''$, the spot *i* was about the middle of its parallel. Fig. 5, No. 2, shews the spots and belts when Jupiter was emerging from behind the Moon, *o p* being the outward limb of the Moon, and *m n* the boundary between light and darkness.

Plate V. Fig. 5, No. 1.

Different opinions have been entertained by astronomers respecting the cause of the belts and spots of Jupiter. By some they have been regarded as clouds, or as openings in the atmosphere of the planet, while others imagine that they are of a more permanent nature, and are the marks of great physical revolutions, which are perpetually agitating and changing the surface of the planet. The first of these opinions sufficiently explains the variations in the form and magnitude of the belts, but it by no means accounts for the permanence of some of the spots, and the parallelism of the belts of Jupiter. The first observed by Cassini, which reappeared eight times between the years 1665 and 1708, could not possibly be occasioned by any atmospherical variations; and its disappearance for five years, between 1708 and 1713, is a presumptive, though not a decisive argument, that it arose from some changes in the body of the planet. We are, however, rather disposed to think, that from the frequent appearance of this spot, it is permanent upon the body of Jupiter, and that its disappearance is owing to the interposition of clouds in the atmosphere of the planet. If it

were the effect of an earthquake or inundation, and if it were the mark of a new island or continent, as has been conjectured, upon what principle can we account for its reappearance in 1713, in precisely the same form and position? May we not then suppose, that the clouds of Jupiter, partaking of the great velocity of his diurnal motion, are formed into strata parallel with the equator; that the body of Jupiter reflects less light than the clouds, and that the belts are nothing more than the body of the planet seen through the parallel interstices which lie between the different strata of clouds. The permanent spot seen by Cassini will of course only be seen when it is immediately below one of these interstices, and will therefore always appear as if it accompanied one of the belts.[2]

On the satellites of Jupiter.

The four satellites of Jupiter, of which a short account has been already given in Vol. I, may in general be seen with a telescope which magnifies 30 times. The third and fourth, indeed, have been sometimes seen with the naked eye (*Phil. Mag.* xxv, p. 175), but it is only when the air is uncommonly pure that we can expect to be indulged with such a sight. These small bodies have been observed by astronomers with great assiduity during the last century, and the tables of their motions have been brought to a degree of perfection which the most sanguine expectations of astronomers could never have anticipated. The tables of Wargentin for finding the eclipses of these bodies, and the more recent and accurate ones of De Lambre, founded on La Place's theory of their mutual attractions, have been of essential use to geographers, in enabling them to determine with accuracy the longitude of places upon the surface of the Earth. To astronomers the system of Jupiter and his satellites is equally interesting. Though a century and a half has scarcely elapsed since their discovery, yet, from the extreme shortness of their revolutions, they present to us great and interesting changes, which are not effected in the course of many centuries in the planetary system.

The following table contains a full view of the elements of the satellites of Jupiter, as deduced from the theory of La Place, and from the most recent observations of modern astronomers.

[2] This spot has always been seen in connexion with the great southern belt of Jupiter. The belt indeed has been observed without the spot, but this was probably owing to a variation in the distance of the belt from the equator of Jupiter.

Table of the Elements of the Satellites of Jupiter.

	I. *Satellite.*	II. *Satellite.*	III. *Satellite.*	IV. *Satellite.*	
Periodical revolution,	$1^{d}\ 18^{h}\ 27'\ 33''$	$3^{d}\ 13^{h}\ 13'\ 42''$	$7^{d}\ 3^{h}\ 42'\ 33''$	$16^{d}\ 16^{h}\ 32'\ 8''$	According to Wargentin.
Do. do.	1^{d} 769137787	3.551181017	7 154552608	16.689019396	Used by La Place.
Synodical revolution.	$1^{d}\ 18^{h}\ 28'\ 35''.9453748$	$3^{d}\ 13^{h}\ 17'\ 53''.7301060$	$7^{d}\ 3^{h}\ 59'\ 35''.8251128$	$16^{d}\ 18^{h}\ 5'\ 7''.0209844$	Delambre.
	Circles.	Circles.	Circles.	Circles.	
Motion in 100 Julian years,	20655 7^{s} 24° 49′ 45″	10285 3^{s} 22° 31′ 40″	5105 1^{s} 21° 19′ 37″	2188 6^{s} 24° 50′ 0″	According to Wargentin.
	20645 7^{s} 25° 28′ 11″	10285 3^{s} 23° 13′ 53″	5105 1^{s} 22° 6′ 49″	2188 6^{s} 24° 42′ 49″	According to De Lambre.
Epoch for 1760,	6^{s} 26° 18′ 24″	4^{s} 17° 4′ 48″	6^{s} 12° 27′ 43″	9^{s} 7° 27′ 4″	According to Wargentin.
Epoch for the midnight, beginning Jan 1, 1750,	0 15 15 45	10 11 26 49	0 10 16 20	2 12 33 4	According to De Lambre.
Daily motion,	6^{s} 23° 29′ 20″ $18\frac{1}{2}'''$	3^{s} 11° 22′ 29′ $4\frac{3}{5}'''$	1^{s} 20° 19′ 3″ $27\frac{3}{10}''$	0^{s} 21° 34′ 10″ 0‴	According to Wargentin.
Distance of each satellite, the radius of Jupiter being unity,	5.965	9.494	15.141	26.630	According to Newton.
	5.67	9.000	14 38	25.3	According to Cassini.
	5.698491	9.066548	14 461893	25.43590	Deduced by La Place from Kepler's law.
Apparent mean distance,	1′ 51″	2′ 57″	4′ 42′	8′ 16″	According to Wargentin.
Inclination of their orbits,	3° 18′ 38″	3° 48′ 0″	3° 25′ 57″	2° 36′ 0″	According to Maraldi.
Mean inclination,	3° 18′ 38″	3° 18′ 0″	3° 13′ 58″	2° 36′ 0″	According to Wargentin.
Diameter of the satellites, as seen from the centre of Jupiter at their mean dist.	60′ 20″	29′ 42″	22′ 28′	9′ 39″	According to M. Bailly.
	1820″.83464	1298″.36520	1271″.19456	566″.68896	According to La Place's theory.
Radius of the shadow in degrees of the orbits of the satellites,	9° 35′ 37″	6° 1′ 3″	3° 43′ 58	20° 8′ 2″	According to Wargentin.
	10° 3′ 36″	6° 17′ 10″	3° 55′ 8′	2° 12′ 26″	According to La Place's theory.
Semiduration of eclipses,	1^{h} 7′ 33″.2	1^{h} 25′ 19″.4	1^{h} 46′ 20″.3	2^{h} 21′ 45″.4	According to De Lambre.
	1^{h} 10′ 53′.45	1^{h} 28′ 5[illegible]″.1	1^{h} 50′ 9 .1	2^{h} 27′ 13″.1	According to La Place's theory.
Time which each satellite takes to enter the shadow,	220″.01036	306″.20730	604″.50604	630″.00762	According to La Place.
Long. of the node, 1760,	10^{s} 14 30′	10^{s} 13° 45′	10 14° 24′	10^{s} 16° 39′	According to Wargentin.
Annual motion of the node,		2 3″		4′ 19″	
Masses of the satellites, that of Jupiter being 1,	0.0000173 81	0.0000232355	0.0000884972	0.0000426591	Calculated by La Place.

In looking at the satellites of Jupiter through a common telescope, they appear to be of different magnitudes, but their diameters are so extremely small, that it is difficult to obtain an accurate measure of them by the application of the micrometer. The eclipses of these bodies, however, furnish us with a method of estimating their magnitude; for it is evident that the largest satellite will take longer time than the smaller ones to enter into his shadow. In this way M. Bailly determined the diameters which are given in the preceding table (See *Mem. Acad.* 1771, p. 590, 619, 623). The other measures which follow them in the same table were deduced by La Place from the masses of the satellites, and may be considered as very accurate (See *Mécanique Céleste*, tom. iv, p. 171, 172). By comparing the shadows of the satellites when seen upon the disc of Jupiter, Wargentin found that the third and fourth were five or six times larger than the first, and the first twice as great as the second. According to Dr. Herschel, the third satellite of Jupiter is considerably larger than the rest; the first is a little larger than the second, and nearly the size of the fourth; and the second is a little smaller than the first and fourth, or the smallest of the four. Hence the doctor expresses their relative magnitudes thus, $3\,..\,\frac{1}{4}\,..\,2$. (*Philosophical Transactions*, 1797, Part II. p. 351).

When the brilliancy of the satellites of Jupiter is examined at different times, it appears to undergo a considerable change. By comparing the mutual positions of the satellites with the times when they acquire their maximum of light, Dr. Herschel concluded that, like our Moon, they all turned round their axis in the same time that they performed their revolution round Jupiter. Maraldi had formerly deduced the same result for the fourth satellite, by observing the period of its variations.

Theorems discovered by La Place.

From the theory of the reciprocal attractions of the three first satellites, La Place has discovered two very remarkable theorems concerning their motions. He found, *that the mean motion of the first satellite added to twice the mean motion of the third satellite, is rigorously equal to thrice the mean motion of the second satellite*; that is, making m the mean motion of the first, m' that

of the second, and m'' that of the third, we have by the theorem,

$$m+2m''=3m', \text{ or}$$
$$m+2m''-3m'=0.$$

By taking the mean motion of the satellites for 100 Julian years, as determined by De Lambre, La Place found that

$$m+2m''-3m'= \text{only 9 seconds.}$$

a coincidence between theory and observation which is truly astonishing.

The second theorem deduced by La Place is equally curious, though, from particular causes, it does not accord so well with observation. He found, *that the epoch of the first satellite*, minus *three times that of the second*, plus *two times that of the third, is exactly equal to a semicircle, or* 180 *degrees;* that is, making $l\ l'\ l''$ the mean longitudes or epochs of the satellites, we have

$$l-3l+2l''=180, \text{ by theory.}$$

By taking the real epochs of the three satellites for the midnight, beginning the 1st January 1750, as determined by De Lambre, we obtain

$$l-3l'+2l''=180^{\circ}\ 1'\ 3''.6.$$

This result differs only 63 seconds from the theory; but the cause of this difference is very satisfactorily explained by La Place in the *Mécanique Céleste*, tom. iv, p. 135, 136.

From the last of these theorems it follows, that the three first satellites of Jupiter can never be eclipsed at the same time. For if this were possible, the longitude of three satellites would be equal at the time of their eclipse, that is, $l=l'=l''$, consequently,

$$l-3l'+2l''=0,$$

which is impossible. When the second and third satellites are eclipsed at the same time, their longitudes will be equal; that is, $l'=l''$; consequently, in this sase, the theorem becomes

$$l-l'=180;$$

that is, the difference of the longitudes of the first and second is 180°; but the second being in opposition to Jupiter at the time of its eclipse, the first satellite must be distant from it 180°; consequently, *when the* SECOND *and* THIRD *satellites of Jupiter are simultaneously eclipsed, the* FIRST is always *in conjunction with Jupiter.* On the contrary, it is obvious, that

when the Sun is simultaneously eclipsed by the SECOND *and* THIRD *satellites, that is, when they pass at the same time across his disc, the* FIRST *satellite is in opposition to the planet.*

By following out this principle, we shall find, that *when the* FIRST *and* THIRD *satellites are simultaneously eclipsed, the difference between either of their longitudes and that of the* SECOND is 60°, for in this case $l=l'$, and the equation becomes

$$-3l'+3l''=180^\circ, \text{ or}$$
$$-l'+l''=60^\circ.$$

In like manner, we shall find, that *when the* FIRST *and* SECOND *are simultaneously eclipsed, the difference between either of their longitudes and that of the* THIRD *is* 90°, or *the* THIRD *is in quadrature with Jupiter*. For in this case $l=l'$, and hence

$$-2l'+2l''=180^\circ, \text{ and}$$
$$-l'+l''=90^\circ.$$

It is obvious from these interesting results, that a wonderful provision is made in the system of Jupiter, to secure to that planet the benefit of his satellites. When Jupiter is deprived, at the same instant, of the light of the first and second satellites, or of the first and third, the remaining one of the three first cannot possibly be eclipsed at the same time, but is in such a point of its orbit as to give considerable light to the planet. The simultaneous eclipse of the second and third satellites forms an exception to this remark; for, at the same instant, the first satellite has its dark side turned to the planet. Even in this case, however, the first satellite, when emerging from the Sun's beams, is gradually turning more and more of its luminous hemisphere to Jupiter, to supply the loss of light arising from the want of the other two satellites.

We shall now conclude this account of Jupiter's satellites, with giving the results obtained by La Place, from a comparison of his formulæ with observation.

He found that the orbit of the first satellite moves upon a fixed plane, which passes constantly between the equator and the orbit of Jupiter, by the mutual intersection of these two last planes, whose respective inclination is 3° 5′ 30″, according to observation. The inclination of this fixed plane upon the equator of Jupiter is only 6½ seconds by the theory. The inclination of the orbit of the satellite to its fixed plane is equally small; so that we may conceive the first satellite as in motion upon a plane passing through the equator of Jupiter.

into the melting vessel. I could give sufficient reasons for the whole of this process; but it will be enough to state, the metal will always prove good when so managed.

"The tin will mostly be found in too small a quantity in the above proportions; but as different sorts of copper require different proportions of tin, the proper quantity can only be known by making a trial, which is most conveniently done in the second melting, by taking a small quantity out of the melting vessel with an iron ladle, having an upright handle: half an ounce will be quite sufficient; when cold, grind it upon a plate of metal with a little fine emery, to discover whether it breaks up too much to bear grinding; afterwards break it, to judge of its strength and colour, which may be done in a few minutes: more tin may be added, if required, a little at a time, until it is brought to a proper state for working. By working, I mean grinding and polishing.

"Nothing that I have yet mentioned deserves the name of difficult, compared to the last operation of grinding and polishing; particularly in the working of *Flat metals*, such as the little metals for a Newtonian telescope.

"I have known one of the most experienced workmen bestow the labour of three weeks upon one of these, and, after all, he owned to me it was not flat; this metal was not more than two inches in its transverse diameter. But to obtain any thing perfectly

flat, or straight, or square, or round, or spherical, or any other figure, is not within the reach of Human Industry."

The late indefatigable and ingenious Earl of Stanhope had a plan for constructing a still more stupendous Optical Instrument than even the 40 feet Telescope of Sir Wm. Herschel. Mr. VARLEY informs us, in page 36 of No. 1, January 1820, of the London Journal of Arts and Sciences, that " his Lordship's vast design was no less than the construction of a Telescope of 384 feet in Length, with Reflectors 6 feet in Diameter.

" The observer may sit or stand in a warm room, and, without ever changing his position, observe more than one half of the horizon, the object appearing directly before him, however elevated it may be in the heavens; thus continuing in the easiest posture and without ever being exposed to the open air. No other telescope affords these very desirable advantages.

" In other telescopes, the smallness of the eye-glasses is very objectionable where highly magnifying powers are wanted; in compound eye-pieces particularly, (which are by far the best,) it is next to impossible to obtain them small enough. In the Stanhope telescope, the greatest powers can be obtained with glasses of not less than two inches focus; which are of a size much more manageable in every

pears to be more luminous than Saturn himself. Hence Dr. Herschel has concluded, that it is not any shining fluid, or aurora borealis, as some have concluded, but a solid body, equal in density to the planet. The Doctor is also of opinion, that the edge of the ring is not flat, but of a spherical, or rather spheroidal, form.

In examining the plane of the ring with a powerful telescope, he perceived near the extremity of its arms or *ansa*, several lucid or protuberant points, which seemed to adhere to the ring.[4] At first he imagined them to be satellites; but he afterwards found, upon careful examination, that none of the satellites could exhibit such an appearance; and he therefore concluded, that these lucid points adhered to the ring, and that the variation in their position arose from a rotation of the ring round its axis, which he found to be performed in $10^h\ 32'\ 15''4$. This result is very remarkable; for if we conceive a satellite moving round Saturn, and having for its orbit the mean circumference of the ring, and if we calculate, according to the second law of Kepler, its sydereal revolution, we shall find that the duration of its revolution is nearly equal to the revolution of the ring. According to Dr. Robison, the inner edge of Saturn's ring should revolve in $11^h\ 16'$, and the outer edge in $17^h\ 10'$. Schroeter seems to doubt of the rotation of the ring.

Rotation of the ring.

The surface of the ring of Saturn does not seem to be exactly plane. One of the ansæ sometimes disappears, and presents its dark edge, while the other ansa continued to appear, and exhibited a part of its plane surface On the 9th October 1714, the ansæ appeared twice as short as usual, and the eastern one much longer than the western; and on the 12th October, Saturn was seen with only its western ansa. On the 11th of January 1774, M. Messier observed both the ansæ completely detached from the planet, and the eastern one larger than the other. In 1774, Dr. Herschel likewise observed Saturn with a single ansa. From these observations, it is natural to conclude, that there are irregularities on the surface of the ring, and that the disappearance of the ansæ arises from a curvature in its surface.

[4] When the ring of Saturn was extremely oblique to the eye, M. Messier observed upon it several luminous points, which were greater than the delicate line of light that formed the ansæ of the ring.

La Place's theory of the ring.

These inequalities in the surface of the ring are considered by La Place as absolutely necessary for maintaining the ring in equilibrium round Saturn; and he has shewn, that if the ring were a regular body, similar in all its parts, its equilibrium would be disturbed by the slightest force, such as the attraction of a comet or a satellite; and that it would finally be precipitated upon the surface of the planet. Hence this celebrated philosopher has concluded, that the different rings[5] with which Saturn is encircled, are irregular solids, of unequal breadth in different parts of their circumference, so that the centres of gravity do not coincide with their centres of figure; and that these centres of gravity may be considered as so many satellites circulating round Saturn, at distances depending on the inequality of the parts of each ring, and with periods of rotation equal to those of their respective rings. Hence the ring will turn round its centre of gravity in the same time that it revolves round Saturn. It is obvious, that the action of the Sun and the satellites of Saturn upon these rings, ought to produce motions of precession analogous to those of the Earth's equator; and that as these motions ought to be different for each ring, they ought finally to move in different planes. This result, however, is contrary to observation; and, accordingly, La Place has discovered, that the action of the equator is the cause which retains all the rings in one plane. It was from this phenomenon, of which the cause is now apparent, that he ascertained the rotation of the planet, before Dr. Herschel had determined it by direct observation. See *Mécanique Céleste*, tom. ii, p. 165, 373, and *Mem. Acad. Par.* 1787.

Opinions about the formation of the ring.

Not content with explaining the various phenomena presented by the ring of Saturn, astronomers have travelled beyond the precincts of their science to explain the manner in which the ring was formed. Maupertuis, in his *Discours sur la Figure des Astres*, has maintained, that this luminous girdle was the tail of a comet, which the attraction of Saturn had compelled to circulate around him. Mairan asserted that the diameter of the planet was originally equal to the diameter of its outer ring; and, that by

[5] Mr. Short assures us, that with an excellent telescope, he observed the surface of the ring divided by several dark concentric lines, which seem to indicate a number of rings proportional to the number of dark lines which he perceived.

some unknown cause, the exterior shell of Saturn was broken to pieces which were attracted by his body: But the equatorial parts of the exterior shell remained entire, and thus formed a ring about the planet. Buffon imagines that the ring is a part of the equator which has been detached by the excess of centrifugal force. Without spending time in the discussion of these hypotheses, it may be sufficient to observe, that we may as well attempt to account for the formation of the satellites as of the ring of Saturn; that none of them seem to have been the effect of any accidental cause; and that the most rational solution of the difficulty is to suppose, that when Saturn was created and launched into the heavens, he was at the same instant encircled with a luminous ring, to answer some important purpose, which astronomers have not yet had the sagacity to discover.

The disappearance and reappearance of Saturn's ring having been already explained in Vol. I, § 204, we shall conclude this interesting subject, by pointing out the method of determining the phases of Saturn's ring for any given time. The Table which is employed for this purpose, serves also to find the form of the orbits of the four first satellites of Saturn, as seen from the Earth. (See *Tables de Berlin*, tom. iii, p. 157.)

Table for finding the apparent Figure of the Ring and the Orbits of the four first Satellites of Saturn.

Argument. Long. of Saturn + 13° 43′ 30″.				
Degrees.	Signs. 0 VI. — +	Signs. I. VII. — +	Signs. II. VIII. — +	Degrees.
0	0.000	0.260	0.451	30
3	0.027	0.284	0.464	27
6	0.054	0.306	0.476	24
9	0.081	0.328	0.486	21
12	0.108	0.348	0.495	18
15	0.135	0.368	0.503	15
18	0.161	0.387	0.509	12
21	0.187	0.405	0.514	9
24	0.212	0.421	0.518	6
27	0.236	0.437	0.520	3
30	0.260	0.451	0.521	0
Degrees.	XI. V. + — Signs.	X. IV. + — Signs.	IX. III. + — Signs.	Degrees.

In order to find the figure of Saturn's ring, add 13° 43′ 30″ to the geocentric longitude of Saturn, and with this as an argument, enter the table with the signs at the head or foot, and the degrees at the side; and the corresponding numbers in the table will express the smaller axis of the ring, the greater axis being 1000. This result, however, requires a correction, which depends upon the latitude of Saturn. Reduce his latitude, therefore, to minutes, and the fourth part of his latitude, thus reduced, being applied to the preceding result with the sign — if his latitude be north, but with the sign + if his latitude be south, will give the true apparent size of the lesser axis of the ring. *Use of the Table.*

Let it be required, for example, to find the form of Saturn's ring on the 25th December 1809, when the geocentric longitude of Saturn is 8s 9° 28′, and his geocentric latitude 1° 37′, or 97′ north.

To the geocentric longitude of Saturn,	8s 9° 28′ 0″
Add the constant quantity,	13 43 30
Argument,	8s 23° 11′ 30″
Which corresponds in the table with	+0.517
Apply one fourth of the latitude, or $\frac{97}{4}$	—0.024
The smaller axis of the ring,	+0.541

Hence the smaller axis of Saturn's ring is to its greater axis, at the given time, as 541 is to 1000, so that the ring will be very open on the 25th December, and may be easily seen with a telescope. When the sign + is before the result, it indicates, that the most distant half of the ring is farther north than the centre of Saturn, and consequently, that we see the upper or northern surface of the ring. The opposite sign — indicates, that the most distant half of the ring is more south than the centre of Saturn, and the southern side of the ring is then visible. The result which is thus obtained, marks also the figure of the orbit of the four first satellites of Saturn.

When we look with a good telescope at the body of Saturn, he appears, like most of the other planets, to be of a spheroidal form, arising from a rapid rotation about his axis. On the 14th September 1789, Dr. Herschel measured his diameter, and found that the equatorial diameter was 22″.8, and the polar diameter 20″.6, which gives the proportion *Figure of Saturn.*

of nearly 10 to 11. It appears, however, from more recent observations made by the same astronomer, that the polar is to the equatorial diameter as 32 to 35, or as 11 to 12 nearly. Till the year 1805 Dr. Herschel had always regarded Saturn as an accurate spheroid; but on the 12th April of that year, he was struck with a very singular appearance exhibited by the planet. The flattening at the poles did not seem to begin till a very high latitude; so that the real figure of the planet resembled a square, or rather a parallelogram, with the four corners rounded off deeply, but not so much as to bring it to a spheroid. After examining Saturn with his telescopes, and comparing it with the form of Jupiter, Dr. Herschel concluded that this was the real form of the ring (See *Phil. Trans.* 1805.) This form of the planet is represented in Plate II, Figure 7. The following are the proportional dimensions of Saturn's disc:—

Plate II. *Sup.* Fig. 7.

Diameter of the greatest curvature,	36
Equatorial diameter,	35
Polar diameter,	32
Latitude of the longest diameter,	43° 20

Spots and belts of Saturn.

The surface of Saturn is diversified, like that of some of the other planets, with dark spots and belts. Huygens observed five belts, which were nearly parallel to the equator. Dr. Herschel has likewise observed several belts, which in general are parallel with the ring. On the 11th November 1793, immediately south of the shadow of the ring upon Saturn, he perceived a bright, uniform, and broad belt, and close to it a broad and darker belt, divided by two narrow white streaks; so that he saw five belts, three of which were dark, and two bright. The dark belt had a yellowish tinge. (*Phil. Trans.* 1794, p. 28.) These belts generally cover a larger zone of the disc of Saturn than the belts of Jupiter occupy upon his surface.

Spots and rotation of Saturn.

Dr. Herschel has likewise perceived dark spots upon Saturn's disc; and, by the changes in their position, has determined the daily rotation of the planet to be performed in $10^h\ 16'\ 0''.44$, round an axis perpendicular to the plane of the ring. La Place had formerly found from theory, that the interior ring ought to perform its revolution in 10 hours. (*Mem. Acad.* 1787.) The ring of Saturn,

therefore, revolves in the same time nearly as the planet, and round the same axis.

Cause of the great flattening at Saturn's poles.

It is well known, that the flattening at the poles of the Earth, Jupiter, Mars, and Saturn, arises from the centrifugal force of their equatorial parts.[6] On account of the great diameter of Jupiter, and the rapidity of his daily motion, his equatorial parts move with immense velocity; and, therefore, in consequence of their great centrifugal force, this planet is more flattened at his poles than either the Earth or Mars. It is remarkable, however, that Saturn should be more flattened at his poles than Jupiter, though the velocity of the equatorial parts of the former is much less than that of the latter. When we consider, however, that the ring of Saturn lies in the plane of his equator, and that it is equally, if not more dense than the planet, we shall find no difficulty in accounting for the great accumulation of matter at the equator of Saturn. The ring acts more powerfully upon the equatorial regions of Saturn than upon any part of his disc; and by diminishing the gravity of these parts, it aids the centrifugal force in flattening the poles of the planet. Had Saturn, indeed, never revolved upon its axis, the action of the ring would, of itself, have been sufficient to give him the form of an oblate spheroid.

Satellites of Saturn.

The planet Saturn is surrounded with no fewer than seven satellites, which supply him with light during the absence of the Sun. The fourth of these satellites was first discovered by Huygens, on the 25th March 1655. Cassini discovered the fifth in October 1671, the third on 23d December 1672, and the first and second in the month of March 1684. The sixth and seventh satellites, which were discovered by Dr. Herschel in 1789, are nearer to Saturn than any of the rest, though, to avoid confusion, they are named in the order of their discovery. These satellites are all so small, and placed at such a distance from the Earth, that they cannot be seen unless with excellent telescopes. Wargentin saw the five old satellites with an achromatic telescope of ten feet; and, on the 19th December 1793, Dr. Herschel saw them distinctly with a power of 60 applied to his ten feet reflector. The sixth and seventh are the smallest of the whole; the first and second are the next

[6] A machine for illustrating this experimentally, is described in Ferguson's *Lectures*, Vol. I, Lect. II, p. 55.

smallest; the third is greater than the first and second; and the fourth is the largest of them all. The fifth satellite surpasses all of them but the fourth in brightness, when it is at its western elongation from Saturn; but at other times it is extremely small, and entirely disappears at its eastern elongation. This phenomenon, which was at first observed by Cassini, appears to arise from one part of the satellite being less luminous than the rest. In consequence of the rotation of this satellite about its axis, this obscure part of its disc is turned towards the Earth when it is in the part of its orbit east of Saturn; and the luminous part of its surface becomes visible while it enters into the western part of its orbit. Dr. Herschel observed this satellite through all the variations of its light; and concluded that, like our Moon, and the satellites of Jupiter, it turned round its axis in the same time that it performed its revolution round the primary planet. When he used his twenty feet telescope, he never lost sight of the satellite, even when its light was most faint.

Variation in the light of the fifth satellite.

The *first* satellite of Saturn revolves at the distance of 4.893 semidiameters of the planet, in $1^d\ 21^h\ 18'\ 26''$; the *second* at 6.268 semidiameters of Saturn, in $2^d\ 17^h\ 44'\ 51''$; the *third* at 8.754 semidiameters of Saturn, in $4^d\ 12^h\ 25'\ 11''$; the *fourth* at 20.297 semidiameters of Saturn, in $15^d\ 22^h\ 41'\ 13''$; the *fifth* at 59.154 semidiameters of Saturn, in $79^d\ 7^h\ 53'\ 43''$; the *sixth* at 3.080, in $23^h\ 37'\ 23''$; and the *seventh* at 3.952 semidiameters of Saturn, in $1^d\ 8^h\ 53'\ 9''$.

The following Table shews, at one view, the various particulars which are known respecting these satellites.

Table, containing the Longitudes, Distances, &c. of the Satellites of Saturn.

Old Names,	*Sixth Satellite.*	*Seventh Satellite.*	*First Satellite.*	*Second Satellite.*	*Third Satellite.*	*Fourth Satellite.*	*Fifth Satellite.*
Periodical revolution.	22^{h} 37′ 32″9	1^{d} 8^{h} 53′ 8″9	1^{d} 21^{h} 18′ 26.2″	2^{d} 17^{h} 44′ 51″.2	4^{d} 12^{h} 25′ 11″.1	15^{d} 22^{h} 41′ 13″.1	79^{d} 7^{h} 53′ 42″.8
Synodical revolution,	22 37 30	1 8 53 24	1 21 18 54 8	2 17 45 51.0	4 12 27 55,2	15 23 15 20.2	79 22 3 12.9
Periodical revolution, in days and decimals,	D. 1.37024	D. 0.04271	D. 1.88780	D. 2.73948	D. 3.90311	D. 15.9453	D. 79.3295
Ditto, in seconds,	118389″	81443″	163106″	236991″	451749″	1377973″	6854023
Epoch 1788,	65° 02′	307° 48′	131° 91′	173° 95′	93° 86′	132° 41′	196° 84′
Daily motion,	381° 962′	262° 727′	6 10 41 53	4 11 32 6	2 19 41 24	0 22 34 38	0 4 32 17
Motion for 365 days,			4 4 44 42	4 10 15 19	9 16 57 5	10 20 40 41	7 6 23 37
Distance in diameters of the rings, according to Bradley,			1.0485	1.344	1.876	4.349	12.674
In diameters of Saturn,		1 510	2.5465	3.134	4.377	10 1475	29 577
In minutes and seconds,	28″.6689	36″.7889	43″.5	56″	1′.18″	3.0″	8′ 42″.5
In French leagues,	56390	44053	65149	83377	116458	270048	884152
Inclination of orbit,	30°	30°	30°	30°	50°	24°30′ to 25°55′	24° 45′
Place of node, according to La Lande,	5^{s} 17° 5′	5^{s} 17° 5′	5^{s} 17° 5′	5^{s} 17° 6′	5^{s} 17° 5′	5^{s} 17° 5′	4^{s} 25° 5′
According to Cassini,	5 22 0	5 22 0	5 22 0	5 22 0	5 22 0	5 22 0	4 5 0
According to Maraldi,	5 16 20	5 16 20	5 16 20	5 16 20	5 16 20	5 16 20	
According to Huygens,	5 16 30	5 20 30	5 20 30	5 20 30	5 20 30	5 20 30	
New Names,	*First Satellite.*	*Second Satellite.*	*Third Satellite.*	*Fourth Satellite.*	*Fifth Satellite.*	*Sixth Satellite.*	*Seventh Satellite.*

The position of the satellites of Saturn, and the figure of their orbits, may be easily found for any particular time, by tables of their motions calculated by Cassini, and given in the *Tables de Berlin*; and from tables calculated by Dr. Herschel, and published in the *Philosophical Transactions* for 1790. Their configurations may also be found by a very simple instrument called a Saturnilabe, which is described in La Lande's *Astronomy*, vol. iii, p. 203.

La Place's theory of the satellites of Saturn. The theory of the satellites of this planet is less perfect than that of the satellites of Jupiter. The difficulty of observing their eclipses, and of measuring their elongations from Saturn, have prevented astronomers from determining with their usual precision the mean distances and the revolutions of these secondary planets. In the position of their orbits, however, there is something very remarkable. While the orbits of the six inner satellites, that is the first, second, third, fourth, sixth, and seventh, all lie in the plane of Saturn's ring, the orbit of the fifth deviates considerably from this plane. La Place imagines that the accumulation of matter at Saturn's equatorial parts retains the orbits of the six first satellites in the plane of the equator, in the same manner as it maintains the ring in that plane. The action of the Sun, indeed, tends to draw them from the plane; but the effect of this action becomes sensible only on the orbit of the fifth or inner satellite, which sufficiently accounts for the deviation of its path from the general plane in which Saturn constrains the other satellites to move. The orbits of the satellites of Saturn move, like those of the Moon, and the satellites of Jupiter, upon fixed planes, which pass constantly by the nodes of the equator and the orbit of Saturn, between these two last planes. Their orbits preserve their inclination almost invariable, and their nodes have a retrograde motion nearly uniform. See *Mécanique Céleste*, tom. iv, p. 173. 185.

CHAP. IV.

ACCOUNT OF NEW DISCOVERIES, &c. RESPECTING THE BODY OF THE SUN, AND ITS MOTION IN FREE SPACE.

When we look at the Sun with a telescope of moderate magnifying power, furnished with a piece of black glass, to intercept a portion of the solar rays, we occasionally perceive a number of dark spots upon its surface, of various forms and magnitudes. Though these spots have sometimes been sufficiently large to be distinguished by the naked eye, yet they were not discovered till after the invention of the telescope. They seem to have been first seen either by our countryman Harriot, to whom the science of algebra was under great obligations, or by John Fabricius, who published an account of his observations in 1611, at Wittemberg.[1] The dedication of this work is dated 13th June 1611; but the observations of Harriot upon the solar spots began on the 8th of December 1610.[2] It is obvious, indeed, from the work of Fabricius, that he had seen the Sun's spots during the year 1610, but it is not certain that he saw them before Harriot. It is a remarkable circumstance, that Fabricius was acquainted with no method of intercepting a portion of the solar rays, in order to save the eye. He observed the Sun when he was in the horizon, and when his brilliancy was impaired by thin clouds, and floating vapours; and he advises those who repeat his observations to receive at first a small portion of the Sun, and gradually to accustom the eye to a greater portion, till it is able to bear the full blaze of its light. When the altitude of the Sun became considerable, Fabricius was compelled to abandon his observations; and he informs us, that his eye was so much affected by the impression of the solar light, that, during the two following days, he could not see objects with the same distinctness as formerly.

Observations of Harriot and Fabricius.

[1] This work is entitled *Joh. Fabricii Phrysii de Maculis in Sole observatis, et apparente earum cum Sole conversione narratio.* Wittebergæ, 1611, 4to, 43 pag.

[2] See Ephemerides de Berlin, 1788, p. 154.

Observations of Scheiner. At the beginning of the year 1611, Scheiner and Galileo seem to have observed, about the same time, the spots of the Sun. Scheiner was professor of mathematics at Ingolstadt; and having accidentally turned his telescope to the Sun, when thin clouds were flying across his disc, he perceived a number of black spots, and shewed them to several of his pupils. The report of this discovery was widely propagated; and, though Scheiner was solicited by many of his friends to publish an account of the solar spots, yet he was prevented from yielding to their wishes by a dread of the ecclesiastical power. His friend Mark Velser, however, who was one of the magistrates of Augsburg, and to whom Scheiner had transmitted a detail of his observations, published an account of the discovery, on the 5th January 1612, in three letters, under the signature of *Apelles post Tabulam.* Scheiner imagined that the spots which appeared on the Sun did not belong to that luminary, but were planets, like Mercury and Venus, which revolved in orbits not very distant from the Sun.[3] Galileo, who had already made many observations on the solar spots, and to whom Velser transmitted a copy of Scheiner's letters, with the request that he would favour him with his opinion of the new phenomena, was at first averse to hazard his sentiments on a subject which might again provoke the hostility of the church; but, on the 4th of May 1612, he at length ventured to express his opinions to Velser, and to combat the notion entertained by Scheiner, of the cause of the solar spots. Galileo observed, that these spots were not of a permanent form, as they ought to have been if they were satellites; but that they often united, separated, increased, and dispersed like vapours or clouds. He maintains, that these spots are upon the surface of the Sun; that they describe circles parallel to each other; that the motion of the Sun round its axis every month again presents the spots to our view; that some of the spots continue one or two days, and others thirty or forty; that they contract in their breadth, when they approach the Sun's limb, without suffering any diminution of their length; and that they are seldom seen at a greater distance than 30° from the Sun's

Observations of Galileo.

[3] Scheiner, many years afterwards, published a large work on this subject, entitled, *Rosa Ursina, sive Sol ex admirando facularum et macularum suarum phenomeno varius, a Christophero Scheiner, Germano Suevo, e societate Jesu.* 1630. Folio, 774 pag.

equator. Galileo likewise perceived on the disc of the Sun *faculæ* or *luculi*, which are spots brighter than the rest of his disc, and which move in the same manner as the dark spots.[4]

General phenomena of the solar spots.

The spots of the Sun have been distinctly observed by astronomers since the time of Galileo, and many new and curious facts have been brought to light respecting these interesting phenomena. The spots are very various, both in magnitude and shape. Most of them have a very dark nucleus, surrounded by an umbra or a fainter shade. The boundary between the umbra and the nucleus is distinct and well defined, and the part of the umbra nearest the dark nucleus is generally brighter than the more distant portion. However irregular be the outline of the dark nucleus, the outer circumference of the umbra is always curvilineal, without any angles or sharp projections. When any spot begins to increase or diminish, the nucleus and umbra expand and contract at the same time During the process of diminution, the umbra encroaches gradually upon the nucleus; so that the figure of the nucleus, and the boundary between it and the umbra, are in a state of perpetual change; and it often happens that, during these variations, the encroachment of the umbra divides the nucleus into two or more nuclei. When the spots disappear, the umbra continues for a short time visible after the nucleus has vanished, and unless the umbra is succeeded by a *facula*, or luminous spot, the place where it disappears resembles the other portions of the solar surface. Large umbræ are seldom seen without a nucleus in their centre, but small umbræ frequently appear by themselves. When Dr. Long was examining the Sun's image, received upon a sheet of white paper, he observed a large round spot divide itself into two spots, which receded from each other with immense rapidity. The Reverend Dr. Wollaston perceived a phenomenon of a similar kind, with a twelve inch reflector. A spot burst in pieces when he was observing it, like a piece of ice, which, thrown upon a frozen pond, breaks in pieces, and slides in various directions.

Besides these changes in the spots, which are owing to some cause with which we are yet unacquainted, they undergo variations

[4] An account of Galileo's observations, will be found in his book, entitled, *Istoria Dimostrazioni, intorno a li macchie solari*, Roma 1613. In the preface to this work, he observes that he shewed the spots in the Sun to several persons in the quirinal garden of Cardinal Bandini, in April 1611.

of an optical kind, from their change of position on the disc of the Sun. The nature of this variation will be easily understood, by placing a black spot upon a common globe, and observing the different shapes which it assumes, while the globe is made to revolve about its axis. When the spot is near the middle of the Sun's disc, its breadth is then greater, but it diminishes gradually as it advances towards the edge of his disc. This variation in the figure of the spots, and some of the other variations already mentioned, are represented in Plate III, Fig. 17, where A B is a portion of the Sun's disc, and *a*, *a*, *a*, the appearances of a spot on seven successive days, as observed by Hevelius. Hence it is obvious, that these spots are upon the surface of the Sun, and that their motion across his disc, from east to west, is produced by the revolution of the Sun about his axis. The time in which any spot returns to its former position upon the Sun's disc, is about 27 days 7 hours and 37 minutes; but as the Earth has, during this time, advanced in its orbit from east to west, and in some measure followed the motion of the spot, the real time in which the spots perform their revolutions will be found to be 25 days 10 hours. This will be understood by supposing that a spot has just vanished behind the western limb of the Sun; in the course of 27 days 7 hours and 37 minutes it again vanishes behind the same limb; but, during this interval of time, the Earth has advanced in its orbit, and in the same direction with the spot; and therefore, when the spot reaches the Sun's western limb, after one complete revolution the western limb of the Sun, behind which it vanishes, has shifted in absolute space to the westward, so that the spot has performed a complete revolution, and part of a revolution round the centre of the Sun. We have therefore 365^d 5^h 48 + 27^d 7^h $37'$, or 392^d 13^h $25'$ is to 365^d 5^h $48''$ as 27^d 7^h $37'$, the apparent revolution of the spots is to 25^d 9^h $56'$, the real revolution of the spot, or the time in which the Sun performs his rotation about its axis. The axis of the Sun, round which this revolution is performed, is inclined 7° 20′ to the ecliptic, and the node of the solar equator is in the 18th degree of Gemini The solar spots are never seen towards the poles of that luminary. They are generally confined within a zone, stretching about 30° 5′ on both sides of his equator, though sometimes they have been seen in the latitude of 39° 5′

Plate III. *Sup.* Fig. 17.

Rotation of the Sun, deduced from the motion of his spots.

M. Silberschlag of Magdeburgh made several observations on the solar spots in the year 1768, from which he draws the strange conclusions that they have a motion of rotation, and that they change their place on the surface of the Sun, independent of his monthly revolution. He also concluded that the spots had not merely the dimensions of length and breadth, but that they consisted of thick masses of opaque matter. (Bernouilli's *Lett. Astron.* p. 6.)

Theory of the solar spots.

Galileo, Hevelius, (*Selenographia*, p. 83), and Maupertuis, (*Œuvres*, vol. i. p. 61,) seem to have considered the spots as scoria floating in the inflammable liquid matter, of which they conceive the Sun to be composed. This opinion, however, will appear highly improbable, when we consider the regularity with which the spots frequently re appear on the eastern limb of the Sun, and the effect that the centrifugal force of the Sun would have in carrying all these floating exuviæ to the equatorial regions.

Opinion of De la Hire and La Lande.

M. de La Hire and La Lande consider the solar spots as arising from the opaque body of the Sun, the eminences of which are sometimes uncovered, in consequence of the alternate flux and reflux of the liquid igneous matter in which that opaque mass is generally enveloped. The part of the opaque mass which thus rises above the general surface gives the appearance of the nucleus, while those parts of the opaque mass which lie only a little beneath the igneous matter, produce the appearance of the surrounding umbra.

Dr. Wilson's Theory.

This theory has been very ably opposed by our learned countryman, the late Dr. Wilson, professor of practical astronomy in the university of Glasgow, who maintains, with great appearance of truth, that the solar spots are depressions rather than elevations; and that the black nucleus of every spot is the opaque body of the Sun, seen through an opening in the luminous atmosphere with which he is encircled. This explanation was suggested to Dr. Wilson by the phenomena of the great solar spot which appeared in November 1769, and is founded on the following facts: When any spot is about to disappear behind the Sun's western limb, the eastern portion of the umbra first contracts in its breadth, and then vanishes. The nucleus then gradually contracts and vanishes, while the western portion of the umbra still remains visible.

When a spot comes into view on the Sun's eastern limb, the eastern portion of the umbra first becomes visible, then the dark nucleus, and then the western part of the umbra makes its appearance. When two spots are near each other, the umbra of the one spot is deficient on the side next the other; and when one of the spots is much larger than the other, the umbra of the largest will be completely wanting on the side next the small one. If the large spot have little ones on each side of it, its umbra does not totally vanish, but seems flattened and pressed in towards the nucleus; but the umbra again expands from this compressed state as soon as the little spots disappear. From this cause, Dr. Wilson concludes, that the western portion of the umbra may disappear before the nucleus, when a small spot happens to appear on the western side of the nucleus. All these appearances strongly confirm the opinion of Dr. Wilson, that the black part of the spots is the dark body of the Sun, seen through an opening in the luminous matter.

The reverend Dr. Wollaston, and M. de La Lande, however, have maintained, that though the úmbra generally varies according to the manner now described, yet the phenomenon is not universal, and cannot, therefore, be employed as the foundation of a system. La Lande mentions three observations of his own, and four observations by Cassini and De la Hire, in which the umbra did not vanish, as Dr. Wilson describes it. This anomaly, however, may have arisen from some small spots in the neighbourhood of the large one, and cannot possibly be considered as an argument, that the spots are not excavations in the Sun's surface. At all events, it may be shewn, that in some spots the umbra may not change as it approaches the limb, in consequence of the shallowness and gradual shelving of the opening in the luminous atmosphere.

Dr. Wilson's solar globe. In order to confirm experimentally his theory of the solar spots, Dr Wilson constructed a globe, consisting of two strong hollow hemispheres, formed by pasting slips of paper upon a wooden ball, and afterwards fastened together upon an iron axis. A thick paste, made of glue and Spanish white, were laid, in successive coats, upon this outward shell, till it became of considerable thickness. The globe was then made smooth and spherical; and as soon as it was dried, and the crust white, the spots or excavations were made in its surface, by boring instruments of steel, constructed, in all their

cutting edges, from a scale of parts of the diameter of the ball. The bottom of the hollows were then painted black with Indian ink, and the slope, or shelving sides of the excavations, were distinguished from the brightness of the external surface by a shade of the pencil, which increased towards the external border. When this artificial Sun was fixed in a suitable frame, and examined, at a great distance, with a telescope, the umbra and the nucleus exhibited the same phenomena which have been observed in the real Sun.

La Lande has objected to Dr. Wilson's theory, that the great spots seen by De la Hire on the 3d June 1703, and by Cassini in 1719, made an indentation, or notch, in the solar disc, which he conceives to be incompatible with the opinion that this spot was an excavation. Dr. Wilson, however, has shewn, that excavations may cause something like an indentation in the Sun's limb; and maintains, that the notches do not always accompany large spots; and that the unfrequency of their occurrence, and the want of accurate observations, should preclude astronomers from bringing them forward in support of any class of opinions.

We conceive that the most irrefragable objection to the opinion, that the spots are eminences, which rise above the general level of the luminous matter, arises from the uniform diminution of the spots, as they advance from the central part of the Sun to his western limb. If these dark solar mountains are deserted by the luminous matter, why do they appear largest when they reach the centre of the Sun's disc? Whenever the height of the mountains greatly exceeds the diameter of their base, instead of contracting in the dimension of breadth, they ought to increase as they approach the limb; and, at all events, should exhibit phenomena very different from what should take place upon the supposition that the spots are depressions in the luminous matter. It may be said, indeed, that the height of these eminences bears no proportion to the diameter of their base; but this is an assumption of which no theorist is entitled to avail himself.

Faculæ, or bright spots in the Sun.

The faculæ, or parts of the surface of the Sun which are brighter than the rest of his disc, require to be examined with good telescopes. They are generally seen in the places where spots have appeared; and sometimes the facula which envelopes an assemblage of spots, is

distinguished by a very great degree of brilliancy. These faculæ, according to the reverend Dr. Wollaston, are often converted into dark ones. He observed a bright facula appear on the east limb of the Sun, which next day became a spot. (See *Phil. Trans.* 1774, vol. 64, 337, and *Anciens Memoires*, p. 663.) He also observed a mottled appearance over the face of the Sun, which, though most visible near the limb, was also perceptible in the centre, but never appeared towards the poles. The celebrated astronomer M. Messier has made a number of curious observations upon the solar faculæ. He often saw them enter upon the disc of the Sun, disappear as they approached the centre, and afterwards re-appear on his other limb. In general, they continued visible for about three days after they appeared, and were seen, for the same space of time, before they quitted the Sun's western limb. In these faculæ, spots generally arise, of a magnitude proportional to the brightness of the facula. When this did not happen, M. Messier found that the faculæ were the precursors of spots, which ordinarily appeared near the same place on the following day; and hence he was always able to predict the appearance of spots about 24 hours before they entered the Sun's disc, and to anticipate from the situation and brightness of the faculæ, the brilliancy and position of the spots themselves. See *Mem. Acad. Par.* 1784. M. Schroeter has seen these faculæ in every part of the Sun's limb, but particularly in a zone between 20° of north and 20° of south solar latitude. They generally subtended an angle of about two or three minutes, and always appeared most brilliant when they were near the limb. (Beobachtungen, 1789.)

Observations of Dr. Herschel.

Such are the observations which were made upon the solar spots before they were examined by the powerful telescopes of Dr. Herschel. This astronomer continued his observations from 1779 to 1794, and has disclosed a number of curious phenomena, which throw much light upon the nature and construction of the Sun. Before we direct the attention of the reader to the several conclusions which the Doctor has deduced, we shall give an account of the different phenomena which he observed on the surface of that luminary. It will be necessary, however, to premise, that he regards the luminous surface of the Sun as neither a liquid substance, nor an elastic fluid, but as luminous clouds, floating in

the solar atmosphere; and that he considers the dark nucleus of the spots as the opaque body of the Sun, appearing through the openings in his atmosphere. Rejecting the old terms, of *Spots*, *Nuclei*, *Umbræ*, *Faculæ*, &c. Dr. Herschel has framed a new nomenclature, and comprehends all the solar appearances under the names of *Openings*, *Shallows*, *Ridges*, *Nodules*, *Corrugations*, *Indentations*, *and Pores*. (See *Phil. Trans.* 1794; and 1801, Part II. p. 265.)

Openings are those appearances, in which the opaque body of the Sun is visible, in consequence of the removal of part of the luminous clouds. One of these openings, with a shallow about it, which was seen on the 4th January 1801, a good way past the Sun's centre, is represented in Plate III, Fig. 18. On the western side of the shallow, its thickness was visible from its surface downwards; but, on the eastern side, the thickness could not be seen, the edge of the shallow only being visible. A section of this opening is shewn in Fig. 19, where the lines *a b c d f*, corresponding with those in Fig. 18, are supposed to be drawn from the eye of the observer. The line *d* passes through the opening to the opaque body of the Sun It is obvious, from Fig. 19, that the thickness of the shallow is visible only on one side, from the position of the observer's eye. Large openings are generally surrounded with shallows, though many openings, and particularly small ones, have no shallows. Openings have a tendency to run into each other; and new ones often break out near others. Ridges and nodules generally accompany openings. Dr. Herschel imagines that the openings are produced by an elastic gas, which issues through the incipient openings, or pores, and, forcing its way through them, spreads off the luminous clouds. The direction of the gaseous stream is often oblique; so that the luminous clouds are driven laterally, and form a larger shallow on one side. Openings sometimes have a difference of colour. They divide when decreased, and sometimes they increase again; but, in general, when they are divided, they diminish, and disappear, leaving the surface more than usually disturbed. They are sometimes converted into large indentations, and not unfrequently into pores. Fig. 20 represents an opening, with a branch from its shallow: In the course of an hour it assumed

Openings.

Plate III. Sup. Fig. 18-31.

the appearance shewn in Fig. 21. Fig. 22 is another opening, with a long shallow. In three hours it assumed the appearance in Fig. 23; and an hour after this, an opening appeared in the shallow, as in Fig. 24. The openings are generally at their greatest extent, as in Fig. 25, when the shallows begin to vanish, and the lips, or projections, to disappear. The division of the decaying opening is shewn in Fig. 26, where the luminous passage across the opening resembles a bridge thrown over a hollow.

Shallows. Shallows are places from which the luminous solar clouds of the upper regions are removed, and are therefore depressed below the general level of the surface of the Sun. The thickness of the shallows is visible: they sometimes exist without openings. They generally begin from the openings, or branch out from shallows already formed, and go forwards. Fig. 27 shews the two branches, A, B, of a shallow, proceeding from an opening, C. In the course of half an hour, Fig. 28, the shallow B is nearly united to the narrow part of the shallow surrounding the opening D, while the shallow A seems to advance in a direction towards the opening E. In the space of another half hour, the shallow B has completely run into the shallow about D, while the shallow A has increased in breadth towards F. The shallow A became afterwards pointed, as in Fig. 29; and in the course of an hour, it became broad at the point, and a new branch broke out at G. From these changes, Dr. Herschel concludes, that the shallows are occasioned by something issuing from the openings, which drives away the luminous clouds from the parts where it finds the least resistance, or which dissolves these clouds as soon as it reaches them. The new branch afterwards began to increase, and another branch, marked H, Fig. 28, began to break out from the shallow around E. These changes Dr. Herschel attributes to the gas, or substance, which at first forced open the passages, and is now widening them. Three small branches, *a*, *b*, *c*, were seen to project from the shallow of the large opening in Fig. 31. The vacancies between these branches were afterwards filled up, by the same cause that occasioned them, so as to increase the breadth of the shallow on that side of the opening. The shallows have no corrugations, but are tufted, like masses of dense clouds. The decay of the shallows is supposed to arise from

the encroachment of the luminous clouds, in consequence of the enfeebled energy of the gas or substance that produced them.

Ridges.

Ridges are elevations of the luminous clouds above their general level, or above the general surface of the Sun. These elevations generally surround openings, though they have sometimes been perceived where openings do not exist. Ridges soon disperse. One of them occupied a space which subtended an angle of 2′ 46″, corresponding to 75,000 English miles. Dr. Herschel ascribes the formation of the ridges to the disturbance of the luminous clouds, by the elastic gas which issues from the opening; or he conceives that this gas may act below the luminous clouds, so as to elevate them above their ordinary level.

Nodules.

Nodules, formerly called faculæ, or luculi, are small, but brilliant, and highly elevated parts of the luminous clouds. Dr. Herschel imagines that they may be ridges, seen obliquely, or foreshortened.

Corrugations.

Corrugations are elevations and depressions of the luminous matter, having a mottled appearance, and consisting of light and dark places. The dark places appear to be lower than the bright places; and, in a favourable atmosphere, the corrugations may be as distinctly perceived as the rough surface of the Moon. They extend over every part of the Sun's surface. Their shape and position is perpetually changing, and they increase, diminish, divide, and vanish quickly.

Indentations.

Indentations are the dark parts of corrugations; and from the circumstance of their being visible very near the limb of the Sun, it would appear that they are not much depressed below the level of the luminous clouds. The sides of the indentations are like circular arches, (See Fig. 32), with their bottoms occasionally flat. Indentations are of the same nature with shallows, varying in size, and sometimes containing small openings, and at other times changing into openings. They extend over the whole surface of the Sun, and, with small magnifying powers, they have the appearance of points.

Pores.

Pores are small holes or openings in the low places of indentations. Sometimes they increase and become openings, and frequently vanish in a short time.

Dr. Herschel's theory of the solar phenomena.

From these interesting facts, Dr. Herschel has deduced a theory of the solar phenomena; which, however ingenious it may be, is founded on assumptions too arbitrary and gratuitous to be recognised in a science which admits of no evidence but demonstration. To suppose that the numerous irregularities on the surface of the Sun are occasioned by an elastic empyreal gas which rises through the openings, and disturbs the equilibrium of the luminous mass, is to shew how these irregularities may be produced by the action of a hypothetical agent; but it never can be considered as an explanation of the processes which nature is carrying on in that immense depository of fire. But though we cannot admit the hypothesis proposed by this learned and ingenious astronomer, we are disposed to acquiesce in some of the important conclusions which he has drawn from his observations. From the numerous elevations and depressions of the luminous matter, and from the length of time during which they are visible, the Doctor justly infers that the shining matter of the Sun is not a fluid, but a mass of luminous or phosphoric clouds. He conceives, from the uniformity of colour in the shallows, that below these self-luminous clouds there is another stratum of clouds of inferior brightness, which is intended as a curtain to protect the solid and opaque body of the Sun from the intense brilliancy and heat of the luminous clouds. By means of his photometer, Dr. Herschel found that the light reflected by the inferior clouds is 469 out of 1000; and that the light reflected by the opaque body of the Sun is only 7. Hence it appears that the Sun consists of a dark solid nucleus, surrounded by two strata of clouds. The outermost of these is the region of that light and heat which is diffused from the centre to the remotest parts of the system, while the interior stratum is supposed to protect the inhabitants of the Sun from the fiery blaze of the stupendous furnace by which they are inclosed.[5]

[5] It is a curious fact, that the opinions of Dr. Herschel, respecting the nature of the Sun, were maintained about 22 years ago by a Dr. Elliot, who was tried at the Old Bailey for shooting Miss Boydell. The friends of the Doctor maintained that he was insane, and called several witnesses to establish this point. Among these was Dr. Simmons, who declared that Dr. Elliot had, for some months before, shewn a fondness for the most extravagant opinions; and that, in particular, he had sent to him a letter, on the light of the celestial bodies, to be communicated to the Royal

That the Sun may, at the same time, be the source of light and heat, and yet capable of supporting animal life, is one of those conclusions which we are apt to admit without hesitation, and to cherish with peculiar complacency. The mind is filled with admiration of the wisdom of God, and swells with the most sublime emotions, when it conceives that apparently the most inaccessible regions of creation are peopled with animated beings; and that, while the Sun is the fountain of the most destructive of the elements, it is, at the same time, the abode of life and felicity. In impressions of this kind, however, delightful though they be, we must not rashly indulge, lest we should afterwards find that we have been admiring an order of things which does not exist in nature, and have thus been indirectly reflecting on the infinite wisdom that sanctioned an opposite arrangement. Whenever we allow our feelings to interfere with our reasonings, we are apt to yield ourselves to the guidance of loose analogies and imperfect views, and become the defenders of opinions, which every subsequent observation and discovery will only tend to overthrow. We conceive that the opinion of the Sun's being a habitable globe rests on reasonings of this nature; and as the subject is curious and worth examination, we shall endeavour to place it in its proper light.

Natural prejudices in favour of this theory.

When the invention of the telescope enabled astronomers to detect the striking resemblances between the different planets of the system, it was natural to conclude, that as they were composed of similar materials, as they revolved round the same centre, and were enlightened by similar moons, they were all intended by their wise Creator to be the region in which he chose to dispense the blessings of existence and intelligence to various orders of animated beings.

Examination of Dr. Herschel's theory.

Society. This letter confirmed Dr. Simmons in the belief that this unhappy man was under the influence of this mental derangement; and, as a proof of the correctness of this opinion, he directed the attention of the court to a passage of the letter, in which Dr. Elliot states, "that the light of the Sun proceeds from a dense and universal aurora, which may afford ample light to the inhabitants of the surface (of the Sun) beneath, and yet be at such a distance aloft as not to annoy them. No objection, says he, ariseth to that great luminary being inhabited; vegetation may obtain there, as well as with us. There may be water and dry land, hills and dales, rain and fair weather; and as the light, so the season, must be eternal; consequently it may easily be conceived to be by far the most blissful habitation of the whole system." (See the *Gentleman's Magazine* for 1787, p. 636.)

The human mind cheerfully embraced this sublime view of creation, and, guided by the principle that nothing was made in vain, man extended his views to the remotest corners of space, and perceived in every star that sparkles in the sky the centre of a new system of bodies, teeming with life and happiness, and displaying fresh instances of the power and beneficence of their Maker. Having thus traversed the illimitable regions of space, and, considering every world which rolls in the immense void as the scene on which the Almighty has exhibited his perfections, the mind, unable to command a wider range, rests in satisfaction on the faithful analogies which it has pursued. While the planets were thus regarded as habitable worlds, astronomers considered the Sun and the stars as the reservoirs from which light and heat were dispensed to man, and as the great central magnets which bound together, and guided in their course the various planets which surround them. These offices were reckoned sufficient for the great luminary; and astronomers were led by no analogy, and by no consideration of final causes, to view it as the seat of animal existence: they left it to the poets to people, with a colony of salamanders, these regions of eternal fire.

The solar observations of Dr. Wilson first suggested the opinion that the Sun was an opaque and solid body, surrounded with a luminous atmosphere; and the telescopes of Dr. Herschel have tended still farther to establish this opinion. The latter of these astronomers, therefore, imagined that the functions of the Sun, as the source of light and heat, might be performed by the agency of its external atmosphere; while the solid nucleus was reserved and fitted for the reception of inhabitants. This conjecture, however, is consonant with nothing which we find in nature. It is inconceivable, indeed, that luminous clouds, yielding to every impulse, and in a state of perpetual change, could be the depository of that devouring flame, and that insupportable blaze of light which are emitted by the Sun; and it is still more inconceivable that the feeble barrier of planetary clouds could shield the subjacent mass from the destructive elements that raged above.[6]

New theory proposed.

The opacity of the interior globe of the Sun is no reason why it may

[6] "If we inquire," says an eminent author, "into the intensity of the heat which must necessarily exist wherever this combustion is performed, we shall soon be

not act a part in the production or preservation of the solar heat. On the contrary, it appears highly probable and consistent with other discoveries that the dark solid nucleus of the Sun is the magazine from which its heat is discharged, while the luminous or phosphorescent mantle, which that heat freely pervades, is the region where its light is generated. Dr. Herschel's own experiments assure us, that invisible rays, which have the power of heating, and which are totally distinct from those which produce light, are actually emitted from the Sun; and that luminous rays, incapable of producing heat, are discharged from the same source. These facts, therefore, not only confirm the theory which we have stated, but receive, in return from that theory, the most satisfactory explanation. The invisible rays which pervade every part of the solar spectrum, formed by a prism, and which extend beyond its red extremity, are emitted from the *opaque* nucleus, and therefore excite no sensation of light on the human retina; while the coloured rays which form the spectrum itself are discharged from the luminous matter that encircles the solid nucleus, and are therefore endowed with the property of illumination. Hence it is easy to assign the reason why the light and heat of the Sun are apparently always in a state of combination, and why the one emanation cannot be obtained without the other. The heat projected from the dark body, and the light emitted from the luminous atmosphere, are thrown off in lines diverging in every possible direction; so that the two radiations must be uniformly intermingled, and, as in a stream flowing from two contiguous sources, the heat must always accompany its kindred element. That light and heat are two different substances, distinguished by different properties, is a proposition which seems to flow from the most recent experiments. We find the invisible heat

convinced that no clouds, however dense, could impede its rapid transmission, even to the parts below. Besides, the diameter of the Sun is 111 times as great as that of the Earth; and, at its surface, a heavy body would fall through no less than 450 feet in a single second; so that, if every other circumstance permitted human beings to reside in it, their own weight would present an insuperable difficulty, since it would become nearly 30 times as great as upon the surface of the Earth, and a man of moderate size would weigh *above two tons*." Dr. Thomas Young's *Nat. Phil.* vol. i, p. 50, 1, 2.

The quantity of heat which is transmitted to the habitable regions of the Sun for the purposes of vegetation must necessarily accumulate, till it becomes insupportable, as there is no possibility of its escaping back to the luminous atmosphere.

of the Sun existing separately from its light, and possessing a degree of refrangibility less than the least refrangible rays of the prismatic spectrum. Light has likewise been found separate from heat; and though it may be imagined that this arises from the extreme attenuation of the light, yet when the light of the Moon is concentrated by powerful burning mirrors, we ought certainly to have expected that the heat, if any did exist, would be appreciable by delicate thermometers. Every attempt, however, to detect heat in the rays of the Moon has completely failed; and we are therefore entitled to presume that a greater proportion of heat than of light has been absorbed by that luminary. If light and heat, then, be two different substances, endowed with different chemical and physical properties, is it not unphilosophical to suppose, that they are emitted from the same source, when we have actually two different regions in the Sun, to which we can with more propriety refer their origin?

This opinion, which we propose only as a conjecture, founded on the most probable analogies, will receive considerable confirmation, if we can adduce any strong analogical arguments against the supposition that the Sun is a habitable world; for if the nucleus is not fitted for the reception of living beings, it is the more probable, that it acts a capital part in the production or preservation of the solar heat. Some arguments have already been suggested relative to this point. We shall endeavour to illustrate two other considerations, which, we trust, will have some weight in favour of our opinion. Since those who consider the Sun as a habitable world, found this opinion upon analogical arguments, we are entitled to avail ourselves of all the assistance which can be drawn from the same source. If the Sun, then, be a great habitable planet, we may expect to find in it those points of resemblance to the other planets which are regarded as distinctive marks of a habitable world; and if we shall find, that any analogy which subsists with respect to all the other planets fails, when applied to the Sun, we are entitled to consider this difference as a proof that the Sun is not inhabited.

In proceeding from the remotest of the planets to the centre of the system, we find, that a general law prevails respecting the densities of the planets. These densities appear to increase, as the planet is nearer the Sun. Thus, we have for the density of the

Georgium Sidus,	$\frac{22}{100}$	Earth,	$4\frac{1}{2}$,
Saturn,	$\frac{11}{12}$,	Venus,	$5\frac{1}{14}$,
Jupiter,	$1\frac{1}{11}$,	Mercury,	$9\frac{1}{4}$.
Mars,	$3\frac{5}{8}$,		

With a single exception in the case of the Georgium Sidus, whose density is not yet accurately ascertained, the densities uniformly increase according as the habitable world approaches to the centre of light and heat. We should, therefore, have expected, from analogy, that the habitable part of the Sun would have exceeded Mercury in density; because it is nearer than that planet to the source of light and heat. This, however, is far from being the case; the density of the Sun is only $1\frac{2}{7}$, a little greater than the density of water. Here, then, we have a complete breach in the analogy which we anticipated; and it is no objection to this argument, to say, that the situation of the Sun, in the centre of the system, may exempt it from the general law of density; because this is a virtual admission, that analogical reasoning, on which Dr. Herschel's opinion is founded, cannot be fairly applied in such a case.

If the Sun is a habitable globe, we can scarcely avoid drawing the conclusion with Dr. Elliot, that "it must be by far the most blissful habitation in the whole system." We should expect, at least, that the solar inhabitants would be rational beings, endowed with intelligence equal to that of man, and availing themselves of their central position, to study the interesting phenomena of the various planets which revolve around them, and of the numerous suns which their own globe would seem to resemble. If there is one place in the system more than another where astronomy could be studied with the greatest facility, and carried to the highest perfection, that place would be in the Sun, where, excepting the phenomena arising from its monthly rotation, the real and apparent motions of the heavenly bodies must be exactly the same. But these results of analogy are mere illusions of the mind: Nature has drawn an impenetrable curtain between the inhabitants of the Sun and the worlds which circulate around them; she has doomed them to the most solitary dwelling in the whole circle of creation, and has marked them as either unfit or unworthy to enjoy the noblest privileges of intelligent beings. The planets and the stars are equally invisible from the surface of this luminary, unless when a tran-

sient glimpse of the heavens is obtained through an accidental opening in the solar atmosphere. From the year 1676, to the year 1684, there was not a single spot in the Sun's atmosphere; so that, during eight successive years, the inhabitants of that globe, if they do exist, never once obtained a glance of that starry firmament, from the contemplation of which a Supreme Being could scarcely have excluded any of his rational creation.

To maintain, therefore, that the Sun is peopled by intelligent beings, is to reason in defiance of the strongest analogies, and support opinions which posterity will rank among the aberrations of the human mind. Might we not as well suppose, that the central caverns of our own planet, which cosmogonists have filled with fire or with water, are the abode of a rational population, who, like the inhabitants of the Sun, are occasionally permitted to obtain a transient view of the heavens, through the craters of volcanoes, or the chinks and fissures which may accompany the convulsions of the globe?

On the connexion of the solar phenomena with the productiveness of the seasons.

Before concluding our remarks upon the construction of the Sun, we must take notice of another opinion of Dr. Herschel's respecting the solar spots, which has been less generally received than that which we have been combating. Imagining that the luminous atmosphere of the Sun is the region of light and heat, he concluded, that when the ridges, corrugations, and openings in this atmosphere are numerous, the heat emitted by the Sun must be proportionally increased, and that this augmentation must be perceptible by its effects upon vegetation. He expected, therefore, that in those years when the solar spots were most numerous, vegetation would be most luxuriant; and that this effect might be ascertained from the price of wheat, as marking the productiveness of the season. By comparing the solar appearances, as given by La Lande, with the table of the price of wheat in Smith's Wealth of Nations, he obtained results which, on the whole, appear favourable to his hypothesis. We do not readily see upon what principle Dr. Herschel concludes that the existence of spots indicates an abundance of luminous matter. We should rather have been disposed to think, that in proportion to the number and magnitude of the openings, the light and heat of the Sun would have been diminished, as so much of the Sun's surface is then disqualified for the discharge of its usual functions. If there is

really an increased luxuriance of vegetation in those years when the solar openings, &c. are most numerous, an opinion which we are much disposed to call in question, we conceive that the theory which we have already explained affords a very satisfactory explanation of the fact. The heat being supposed to be emitted from the dark body of the Sun, it is obvious, that when there is any opening in his luminous atmosphere, the heat emanating from the internal nucleus must be more copiously discharged, in consequence of receiving no obstruction from the luminous clouds; or, if we regard the variations in the Sun's surface as produced by variations in the heat which rises from the nucleus, we may naturally suppose, that when the heat of the Sun is most intense, it will produce the greatest changes in the luminous atmosphere.

Darkening apparatus for viewing the Sun.

Dr. Herschel has invented a very ingenious contrivance for moderating the heat and light of the Sun, when it is examined by means of powerful telescopes. (*Phil. Trans.* 1801, p. 302.) He abandoned the common method of using dark-coloured glasses, and had recourse to fluids. For this purpose, he employed a small square trough, having, in two of its opposite sides, well polished plates of glass. A small handle on one side of the trough, and a spout in the other, were made, for the purpose of pouring out any portion of the liquid when the rest was to be diluted. The trough was then placed in an excavation in the eye-piece of the telescope, so that the rays of the Sun might pass through the fluid before they reached the eye of the observer. By colouring the fluid, the light may be softened at pleasure, and the heat is completely removed by the water. Dr. Herschel found that ink, diluted with water, and filtered through paper, gave a distinct image of the Sun, as white as snow. By this mixture, he could observe the Sun in the meridian, without the smallest injury to his eye, or to the glasses, even when he used a mirror nine inches in diameter, and when the eye-pieces were open, as in night observations.

On the Zodiacal Light.

As the phenomenon called the *Zodiacal Light* has been generally supposed to arise from the Sun's atmosphere, we consider this as the proper place for giving an account of the appearance. Though this light seems to have been observed by Descartes (*Principia*, § 136, 137;) and by Childrey, about 1659 (*Britannia Baconica*, 1661;) yet it did

not attract general notice till the year 1693, when it was observed by Cassini, and received its present name. The zodiacal light, which is less bright than the milky way, is seen at certain seasons of the year, before the rising, and after the setting of the Sun. It resembles a triangular beam of light, rounded a little at the vertex. Its base is turned towards the Sun, and its axis is inclined to the horizon, and lies in the direction of the zodiac. The vertical angle of this luminous cone is sometimes 26°, and sometimes 10°; its length, reckoning from the Sun, which is its base, is sometimes 45°, and at other times 150°. M. Pingre saw one in the torrid zone, which was 120° long, and whose horizontal breadth was from 8° to 30° (See Traité Physique et Historique de L'Aurore Boreale, par M. de Mairan, 1731, 1754.) The best time for seeing the zodiacal light is about the 1st of March, at seven o'clock in the evening, when the twilight is ending, and the equinoctial point in the horizon. The luminous triangle will then appear to be directed towards Aldebaran, as in Plate III, Fig. 33, its axis forming an angle of 64° with the horizon; but if it is viewed in the morning, before sunrise, the angle which it makes with the horizon will be only 26°. In the year 1781, M. Flauzeres observed it in the month of January. On the 21st of March, at half-past seven o'clock, it ended beyond the Pleiades, and was 61° long, 10½° broad, and 8° high. According to M. Foulquier, the zodiacal light is always seen at Gaudaloupe, unless when the weather is bad. M. Humboldt observed the zodiacal light at Caraccas on 18th January, after 7^h P. M. The point of the pyramid was at the height of 53°. The light totally disappeared at 9^h 35′ apparent time, about 3^h 50′ after sunset, without any diminution in the serenity of the sky. On the 15th February it disappeared 2^h 50′ after sunset, and the altitude of the pyramid was 50° on both those occasions; the intensity of the zodiacal light varied in a very sensible manner, at intervals of two or three minutes. These changes took place in the whole pyramid, especially towards the interior, far from the edges; sometimes the light was very faint, and sometimes it exceeded that of the milky way in Sagittarius.—(Humboldt's *Personal Narrative*, Vol. IV, p. 95.)

Plate III. Fig. 33.

As this phenomenon uniformly accompanies the Sun, it has been naturally ascribed to an atmosphere round this luminary, extending beyond the orbit of Mercury, and sometimes even

beyond that of Venus. The zodiacal light is supposed to be a section of this atmosphere, which, being extremely flat at its poles, cannot be supposed to partake of the Sun's monthly motion. M. Laplace has shewn that the Sun's atmosphere cannot reach even the orbit of Mercury, and that it could not in any case display this particular form. Dr. Thomas Young (Lect. on Nat. Phil. vol. i, p. 502) remarks, that the only probable manner in which it can be supposed to retain its figure, is by means of a revolution much more rapid than the Sun's rotation. Some philosophers have ascribed the phenomenon, without any reason, to the refraction of the Earth's atmosphere.

Besides the revolution of the Sun round his axis in 25 days, and his irregular motion about the centre of gravity of the Solar system, he appears to have a progressive motion in absolute space. As all the bodies of the system necessarily partake of this motion, it can only be perceptible from a change in the position of the fixed stars, to which the system is advancing, or from which it recedes. This change of place, or proper motion in the fixed stars, as it has been called, was first observed by Halley, and afterwards by Le Monnier. Tobias Mayer, however, advanced a step farther than these astronomers. He compared the places of about 80 stars, as determined by Roemer, with his own observations, and he found that the greater number of them had a proper motion. He was aware that this change of place might be explained by a progressive motion of the Sun towards one quarter of the heavens;[7] but as the result of his observations does not accord with this hypothesis, he remarks, that many

On the displacement of the Sun, or his progressive motion.

[7] Tandem, quum et quæri possit, quæ hujus motus causa sit, hoc unum monere visum, illum explicari non posse per motum totius nostri systematis solaris, etsi nec impossibile sit Solem, ut ejusdem cum fixis naturæ, instar harum quarundam, in spatio mundano promoveri. Nam si Sol et cum ipso planetæ omnes nostrumque domicilium terra, recta tenderent versus plagam aliquam universæ fixæ, quæ in ea plaga adparent, paullatim a se invicem discedere, et quæ sunt in opposita parte cœli coire viderentur; non secus ac per silvam ambulanti arbores quæ ante viam sunt, disjungi videntur, quæ a tergo, congredi. Hujusmodi communi legi cum obstricti non sint hi fixarum motus, ut propius inspecto abaco patet: Palam est eos non esse mere adparentes, aut ab hac similive communi causa oriundos, sed fixis proprios. Ipsa autem vera atque genuina horum causa forte per plura adhuc secula ignorabitur. (*Mayeri* Opera Inedita, vol. i, p. 79.)

centuries must elapse before the true cause of this motion is explained.

The late Dr. Wilson of Glasgow suggested, upon theoretical principles, the possibility of a solar motion; and La Lande deduced the same opinion from the rotatory motion of the Sun: but these conjectures have been almost completely confirmed by another species of argument.

If the Sun has a motion in absolute space, directed towards any quarter of the heavens, it is obvious that the stars in that quarter must appear to recede from each other, while those in the opposite region seem gradually approaching. The proper motion of the stars, therefore, in those opposite regions, as ascertained by a comparison of ancient with modern observations, ought to correspond with this hypothesis.

Dr. Herschel has examined this subject with his usual success, and he has certainly discovered the direction in which our system is gradually advancing. He found that the apparent proper motion of about 44 stars out of 56 are very nearly in the direction which should result from a motion of the Sun towards the constellation Hercules, or, more accurately, to a point in the heavens whose right ascension is 250° 52′ 30″, and whose north polar distance is 40° 22′. (See *Phil. Trans.* 1788, p. 203; and *Phil. Trans.* 1805.)

By considering the motion of the satellites round their primary planets, and of the primary planets round the Sun, Dr. Herschel supposes that the proper motion of the Sun is not rectilineal, but that it is performed round some distant and unknown centre. Just, however, as the conception appears to be, we can scarcely allow ourselves to think that there is an immense central body of sufficient magnitude to carry around it all the systems with which astronomers have filled the regions of space; but we may suppose, with La Lande, that there is a kind of equilibrium among all the systems of the world, and that they all have a periodical circulation round their common centre of gravity. (*Astronomie*, par La Lande, tom. iii, p. 307, § 3283.)

We shall have occasion to resume this subject when we come to treat of the proper motion of the fixed stars.

CHAP. V.

ON THE NEW DISCOVERIES AND PHENOMENA IN THE MOON.

Phases of the Moon.

THE motions and the phases of the Moon have been already described in the first volume of this work. The proportion between the enlightened and obscure part of her disc may be found, for any given time, from the table, which has been already explained, when treating of the planet Venus. By subtracting the longitude of the Sun from that of the Moon, we obtain the argument of the table, or the Moon's distance from the Sun, with which we enter the table, and take out, in the way already explained, the proportion between the dark and illuminated parts of her disc. See page 109 of this volume.

Explanation of the phenomenon called the old Moon in the new Moon's arms.

If we observe the Moon, in serene weather, when she is about three or four days old, the part of her disc which is not enlightened by the Sun is faintly illuminated by the light that is reflected from the Earth, and the horns of the enlightened part appear to project beyond the old Moon, as if they were part of a sphere considerably larger in diameter than the unenlightened part.[1] It was long deemed a sufficient explanation of this appearance to say, that bright objects affected the retina, to a greater distance than those which were less luminous; and that, therefore, as ink sinks upon soft paper, the image of the bright part of the Moon expands on the retina, and gives it the appearance of projecting beyond the darker portion of her disc. The explanation of this phenomenon, as given by Dr. Jurin,[2] is much more satisfactory. He supposes that the eye cannot accommodate itself, with sufficient distinctness, to view objects at such a distance as the Moon. The pencils of rays, therefore, unite before they reach the retina, and will form an indistinct and enlarged image of the Moon. It is perfectly demonstrable, and may be proved by the simple experiment of looking at the figure of the Moon, cut out of white paper, and

1 This phenomenon is vulgarly, though expressively called "The Old Moon in the New Moon's arms."

2 Essay on Distinct and Indistinct Vision, in Smith's Optics, vol. ii, *Rem.* p. 115.

placed upon a dark ground, that when this luminous body is viewed, either at a distance too remote, or too near, for perfect vision, its image upon the retina will be enlarged, and the illuminated part will encroach upon the obscure portion, and appear to embrace it, in the very same way as it is seen in the heavens. Dr. Jurin, however, has taken it for granted, that the eye cannot see the Moon with perfect distinctness; a position which, however probable it may be, does not rest upon the evidence of experiment.

The illuminated portion of the Moon's disc, when she is three or four days old, obviously receives its light from the Earth, which, to the lunar inhabitants, will then appear to be nearly like a full Moon. As the age of the Moon increases, this secondary light is gradually enfeebled, both in consequence of the diminution of the luminous part of the Earth, and of the increase of the enlightened part of the Moon. On one occasion, however, the weather being uncommonly favourable, we observed the secondary light when the Moon was nine days and fourteen hours old.

Explanation of the lucid bow in the old Moon.

This secondary light of the Moon has been explained by Riccioli and Leslie, upon the supposition that the Moon is phosphorescent. They conceive, that it is impossible to account in any other way for the extreme brilliancy of her disc; and the latter of these philosophers has explained, upon this hypothesis, the thread of light, or the lucid bow which seems to connect the two horns of the Moon. As we shall give a very different explanation of this curious phenomenon, it may be proper to state Mr Leslie's theory in his own words. "After emerging from conjunction with the Sun, her sharp horns are seen connected by a silver thread, or lucid bow, which completes the circle; and a very faint light seems to be suffused over the included space. This bright arch, however, becomes always less vivid; and before the Moon is five or six days old, it has almost totally vanished. The pale outline of the old Moon is commonly ascribed to the reflection, or secondary illumination from the Earth But if it were derived from that source, it would appear densest near the centre, and gradually more dilute towards the edge. I rather should refer it to the spontaneous light which the Moon may continue to emit for some time after the phosphorescent substance has been excited by the action of the solar beams.

The lunar disc is visible, although completely covered by the shadow of the Earth; nor can this fact be explained by the inflection of the Sun's rays in passing through our atmosphere; for why does the rim appear so brilliant? Any such inflection could only produce a diffuse light, obscurely tinging the boundaries of the lunar orb; and, in this case, the Earth, presenting its dark side to the Moon, would have no power to heighten the effect by reflection. But even when this reflection is greatest about the time of conjunction, its influence seems extremely feeble. The lucid bounding arc is occasioned by the narrow *lunula*, which, having recently felt the solar impression, still continues to shine, and, from its extreme obliquity, glows with concentrated effect."[3]

The phenomenon described in the preceding passage is represented in Plate II, *Sup.* Fig. 9, where a diluted light appears to be shed over the obscure portion of the Moon's disc, while a lucid bow, more bright than the rest of the obscure part, seems to join the lunar horns. When we examine this luminous horn in the heavens, the lower part of it at *a*, is always much broader than the upper part at *b*; and when the Moon has considerable libration, so as to withdraw from the Earth a portion of the eastern limb, the bow ceases to be continuous, and the part at *b* is no longer visible. These two appearances, which I have often observed, are sufficient to overthrow the explanation which has been already given; for, upon that hypothesis, the lucid bow ought to have been broadest in the centre, diminishing towards the horns, exactly like the enlightened part of the Moon's disc. We are fortunately, however, not confined to arguments of this kind, satisfactory though they be. The true explanation of the phenomenon is so simple and convincing, that it is scarcely possible not to give it an implicit reception. If we look at the large map of the Moon, given in this work, or any other map which exhibits even a tolerable representation of the lunar surface, we shall find that the eastern limb of the Moon is separated from the central parts of her disc by darker regions, and that the luminous portion comprehended between these darker regions, and the circular line which bounds her eastern limb, has actually the form of a bow, which is broadest towards her southern

Plate II. *Sup.* Fig. 9.

[3] Inquiry into the Nature and Propagation of Heat, p. 453, and Note XLIII, p. 557.

limb, and gradually diminishes in breadth towards her northern horn. The immediate cause, therefore, of the lucid bow, is to be sought for in the accidental circumstance of the Moon's eastern limb being more luminous than the adjacent regions towards the centre. The central parts of the Moon, indeed, are equally luminous with her eastern limb; but their brilliancy is impaired by their proximity to the illuminated portion. It is obvious, that this explanation of the phenomenon may be equally just, whether the secondary light of the Moon is caused by phosphorence, or by reflection from the Earth. Hence we see the reason why the bow is broadest at *a*, and narrowest at *b*, and why the libration of the Moon withdrawing the narrow part *b* of the bow, destroys its continuity. This will be easily understood, by inspecting Plate II, *Sup.* Fig. 9, and comparing it with the large map of the Moon.

General appearance of the lunar surface.

When we look at the surface of the Moon with a good telescope, we find that its appearance is wonderfully diversified Besides the large dark spots, which are visible to the naked eye, we perceive extensive valleys, and long ridges of highly elevated mountains, projecting their shadows on the plains below. Single mountains occasionally rise to a great height, while hollows, more than *three* miles deep, and almost exactly circular, are excavated in the plains. The margin of these circular cavities, is often elevated a little above the general level, and a high eminence rises in the centre of the cavity. When the Moon approaches to her opposition with the Sun, the elevations and depressions upon her surface in a great measure disappear, while her disc is marked with a number of brilliant points, and permanent radiations.

Maps of the Moon.

These various appearances have been accurately represented in maps of the Moon's surface. This was first attempted, but in a very rude manner, by Riccioli. Hevelius, in his Selenography, afterwards gave more just delineations of the lunar disc, during the whole of her progress round the Earth. A map of the Moon, as she appears when full, was drawn by Cassini, and has been copied, though extremely incorrect, into most of our modern treatises on astronomy. Excellent drawings of the Moon were made by Mr. Russel; but the most accurate and complete that have yet been published, are those of the celebrated Schroeter, who has given highly

magnified views of most parts of the Moon's surface. The large engraving of the Moon, which accompanies this work, was drawn with great care by the editor, and appears to be a tolerably correct resemblance of the lunar surface.

As the attention of astronomers has been much directed to the nature and construction of this luminary; and as an accurate acquaintance with the spots is necessary in finding the longitude from lunar eclipses, we shall give very extensive tables of the names and positions of the spots of the Moon.

Explanation of the following Tables.

The first table is formed from the observations of Lambert, and contains the longitude and latitude of 207 spots, with the names given them by Riccioli and Hevelius.

The observations in the second table were made by the celebrated Tobias Mayer. The positions of the spots, marked in italics, were ascertained by a great number of observations, and were the leading points from which the rest were obtained. All the spots given in this table are contained in the preceding one; but the observations of Mayer are much more accurate than those used by Lambert; and the reason will be readily seen why we have not struck these spots out of the first table.

The third table contains the names which have been recently given by Schroeter to the spots which were formerly anonymous. The positions of these spots we have determined in a rough manner, by comparing the spots of the Moon, as given by this astronomer, with the map and table constructed by Tobias Mayer.

The notes at the foot of each table contain general remarks on the nature and appearance of the different spots. The letter E, affixed to the longitude of the spots, denotes that they are to be found on the eastern side of the Moon's disc, on the left hand of the meridian which passes through the Moon's centre; while the letter W signifies that they are placed on the western side of that line. The letter N, affixed to the latitudes, signifies that the spots are in the Moon's northern hemisphere; and the letter S, that they are placed on the south of the equator.

TABLE I. Containing the Longitudes and Latitudes of 207 Lunar Spots, with Remarks on their Position, Appearance, and Structure.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Plutarchus[a]	Mons Alaunus	75 W.	26 N.
Seneca[b]	Mons Alaunus	72 W.	28 N.
Zoroaster	Palus Amadoca	72 W.	58 N.
Berosus	Pars M. Amadoci	70 W.	32 N.
Mercurius	Lacus hyperboreus inferior	67 W.	40 N.
Osimandes	ad. Lac. hyperb. inferior	67 W.	44 N.
Firmicus	Paludes amarae	66 W.	7 N.
Petavius[c]	Pars M. Nerosi	64 W.	21 S.
Vendelinus[d]	Petra Sogdiana	63 W.	17 S.
Langrenus[e]	Insula major	62 W.	8 S.
Furnerius[f]	Pars M. Paropamisi	60 W.	35 S.
Hermes	M. Bodinus.	60 W.	40 N.
Endymion	Lacus hyperboreus superior	60 W.	53 N.
Messala[g]	Pars montium Riphaeorum	57 W.	34 N.
Stevinus	Pars Caucasi inferioris	57 W.	28 S.
Geminus[h]	Pars M. Riphaeorum	55 W.	29 N.
Cleomedes[i]	Pars M. Riphaeorum	55 W.	26 N.
Snellius	Pars M. Paropamisi	54 W.	34 S.
Fabricius	Pars M. Coibacarani	52 W.	52 S.
Mulerius	Pars M. Coibacarani	49 W.	46 S.
Cepheus[k]		49 W.	39 N.
Rheita	Pars M. Coibacarani	48 W.	41 S.
Atlas[l]	Pars M. Macrocemnii	48 W.	47 N.
Proclus[m]	M. Corax	48 W.	16 N.

GENERAL REMARKS.

[a] Annular, with a ridge traversing its southern portion, in a north-east direction. An annular spot on its eastern margin.

[b] Annular, with a regular and an irregular cavity in its eastern margin.

[c] Annular, with large central mountain.

[d] Irregular, open at N. margin, cavity at S. margin, mountain at N. margin.

[e] Annular, with central mountain. Remarkable appearance beyond its S. S. W. margin.

[f] Annular, with cavity north of the centre, and spot south of the centre.

[g] Annular, with a break in its western margin, and an annular spot on its south-west margin.

[h] Annular, with rocks, and a bright radiating spot beyond its E. margin.

[i] A large annular spot, containing three central rocks, with two contiguous annular spots on its north-eastern, one on its north-western, and two on its western margin. Rocks south-east of it.

[k] Southern and northern Cepheus, both annular.

[l] Annular, with central mountain. [m] Small annular spot.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Taruntius	Sinus Phasianus	48 W.	4 N.
Thales		47 W.	62 N.
Santbeck	M. Tancon	47 W.	19 S.
Goclenius	Pars M. Caucasi	46 W.	12 S.
Macrobius[n]	Mons Cimmerius	46 W.	22 N.
Hercules[o]	Pars M. Macrocemnii	42 W.	48 N.
Mutus	Desertum Mingui	42 W.	64 S.
Democritus	M. Bontas	40 W.	61 N.
Metius[o]	Pars. M. Coibacarani	40 W.	43 S.
Pitiscus	M. Dalanguer	40 W.	53 S.
Manzinus	Desertum Mingui	40 W.	70 S.
Euctemon	Pars montium Sarmaticorum	40 W.	83 N.
Alcuinus[o]	M. Hercules	39 W.	3 S.
Beda[o]	M. Hercules	37 W.	2 S.
Martianus Capella	M. Caucasus	36 W.	8 S.
Hagecius	M. Dalanguer	34 W.	54 S.
Neander	Pars montium Sogdianorum	34 W.	33 S.
Isidorus	M. Strobilus	33 W.	8 S.
Censorinus	Pars M. Herculis	32 W.	0
Fracastorius[p]	Lacus Thospitis	32 W.	22 S.
Possidonius[q]	Insula Macra	32 W.	31 N.
Dionysius Exiguus	M. Herculis	31 W.	3 S.
Schomberger	Desertum Mingui	31 W.	77 S.
Vitruvius[r]	Appollonia major	30 W.	19 N.
Piccolomineus	Pars montium Sogdianorum	30 W.	31 S.
Stiborius	Pars montium Sogdianorum	29 W.	39 S.
Homelius	M. Dalanguer	29 W.	50 S.
Tannerus		28 W.	65 S.
Theophilus[s]	Pars M. Moschi	27 W.	12 S.
Plinius[t]	Promontorium Archerusia	26 W.	18 N.
Cyrillus[u]	Pars M. Moschi	25 W.	13 S.
S. Catharina[x]	Pars M. Moschi	24 W.	18 S.
Meton	Pars mont. Sarmaticorum	24 W.	79 N.
Riccius	Pars mont. Uxiorum	24 W.	40 S.
Hypatia	M. Lipulus	22 W.	5 S.
Rabbi Levi	Pars mont. Uxiorum	22 W.	36 S.
Simpelius		20 W.	59 S.
Lilii fratres		20 W. / 12 W.	72 S. / 59 S.

[n] Annular, with central spot, and cavity on east margin.
[o] Annular, with central mountain.
[p] Large hollow, with cavities south of it, and communicating with M. Nectaris.
[q] Annular, containing an annular spot near its south margin, and one in its west and north margin, with several rocks.
[r] Shallow annular spot, with a low central mountain, and numerous rocks to the north of it. [s] Annular, with large central mountain.
[t] Annular, with two central mountains. [u] Irregularly hollow.
[x] Irregularly hollow, communicating with Cyrillus on the north.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Tatius	Mons Moschus	19 w.	15
Sosigenes	Palus Archerusia	19 w.	9 N
Zagutus	Pars mont. Uxiorum	19 w.	32 s.
Alfraganus	M. Lipulus	18 w.	7 s.
Ariadneus		18 w.	5 N.
Dionysius Areopagita[y]	Pars M. Horminii	17 w.	3 N.
Sacrobosco	M. Antitaurus	17 w.	25 s.
Theon junior	M. Tmolus	17 w.	3 s.
Barocius	M. Calchastan	16 w.	48 s.
Maurolycus	M. Calchastan	15 w.	43 s.
Almaeon	M. Antitaurus	15 w.	11 s.
Theon senior	M. Horminius	15 w.	0 N.
Julius Cæsar	Palus Archerusia	15 w.	11 N.
Menelaus[z]	Byzantium	15 w.	16 N.
Pontanus	M. Armeniae	15 w.	29 s.
Aristoteles[a]	M. Serrorum	15 w.	50 N.
Eudoxus[b]	M. Carpathes	15 w.	44 N.
Gemma Frisius	M. Armeniae	14 w.	34 s.
Abulfeda	M. Antitaurus	14 w.	11 s.
Malapertius	Desertum Mingui	14 w.	76 s.
Geber	Antitaurus	13 w.	21 s.
Azophi	Antitaurus	12 w.	23 s.
Curtius[c]	M. Techisandam	12 w.	64 s.
Agrippa[d]	M. Ida	11 w.	7 N.
Sulpitius Gallus		10 w.	19 N.
Archytas	Scopuli hyperborei	10 w.	51 N.
[illegible]ctas	M. Calchistan	10 w.	50 s.
Calippus[e]	M. Haemus	9 w.	39 N.
Manilius[f]	Insula Besbicus	9 w.	14 N.
Aben Ezra		9 w.	21 s.
Apianus	Pars Antilibani	8 w.	29 s.
Stoefler	M. Calchistan	7 w.	47 s.
[illegible]	M. Taurus	6 w.	40 s.
[illegible]		6 w.	39 N.
Hipparchus	M. Olympus	6 w.	6 s.
Aratus	Pars Apennini	5 w.	25 N.
Plinius[h]		5 w.	12 N.

[y] Annular.

[z] Annular, with central mountain, a high rock on its S. E. and two annular spots on its S. W. It is very luminous from its S. W. to its N. E.

[a] Large and annular, with high rock on its south margin, an annular spot on its west, and rocks on its south-east.

[b] Large and annular, with high rocks to the east of it.

[c] Annular, with rock on its N. E. margin.

[d] Annular, with central rock, and ridges from its N. and S. margin.

[e] Annular, with central rock.

[f] Large annular spot, with high margin, and central rock.

[g] Annular, with central spot. [h] Small annular spot.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Alliacensis	Pars Antilibani	5 W.	32 S.
Albategnius	M. Didymus	5 W.	13 S.
Fernelius[i]	Antitaurus	4 W.	37 S.
Werner[k]	Pars Antilibani	3 W.	30 S.
Cysatus	M. Techisandam	2 W.	65 S.
Blanchinus[l]	Antilibanus	2 W.	28 S.
Autolycus[m]	M. Montuniates	2 W.	28 N.
			34 N.[n]
Aristillus[o]	M. Ligustinus	2 W.	55 N.
Timaeus[p]	Lacus niger minor	2 W.	20 N.
Conon[q]	M. Apenninus	0	70 N.
Epigenes	Pars mont. hyperboreorum	0	90 S.
Cabeus	Desertum Mingui	0	36 S.
Walther	M. Tabor	0	42 S.
Orontius[r]	M. Hermon	1 E.	32 S.
Regiomontanus	Pars M. Libani	2 E.	10 S.
Ptolomaeus	M. Sipylus	2 E.	
Arzachel[s] } See Tab. II.	M. Cragus	3 E.	20 S.
Alphonsus	M. Masicythus	4 E.	15 S.
Purbachius[t]	Pars Libani	4 E.	27 S.
Maginus	M. Seir	5 E.	52 S.
Archimedes[u]	M. Argentarius	5 E.	28 N.
Thebit		7 E.	23 S.
Alpetragius	Promont. Aenarium	7 E.	18 S.
Moretus	Desertum Mingui	9 E.	70 S.
Dantes		10 E.	2 N.
Tycho	M. Sinai	10 E.	43 S.
Sasserides[x]	M. Abarim	10 E.	36 S.
Profatius	Ins. Rhodus	10 E.	23 S.
Plato[y]	Lacus niger major	10 E.	52 N.
Gauricus	M. Tabor	11 E.	33 S.
Pilatus	Mare mortuum	12 E.	29 S.

[i] Annular, with small central rock.

[k] Large and regularly circular spot, with central mountain.

[l] Irregular spot, rugged on the west, and connected with a shallow one, covered on the east with many small annular spots.

[m] Large and deep annular spot, with central spot.

[n] Deep and annular, with central rock. [o] Annular.

[p] Deep annular spot in the Apennines.

[q] Two annular spots, encroaching upon each other. The deepest has three central rocks.

[r] Annular spot, containing two small rocks, and an annular spot on its west margin.

[s] Beautiful spot, with very irregular margin, two central cavities, and a central mountain.

[t] Annular spot, containing three rocks, with an annular spot on its north margin, and another on its south-east margin.

[u] Large and deep annular spot, with high margin, and high rocks south of it.

[x] Irregular, consisting of numerous cavities.

[y] Large annular spot, high and rugged on its west margin, with a cavity a little north of it, and another a little to the west.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Eratosthenes[z]	Ins. Vulcania	12 E.	14 N.
Timocharis[a]	Ins. Corsica	13 E.	27 N.
Stadius	In Lacu Hercules	13 E.	c 4 N.
Dominicus Maria	In Lacu Hercules	14 E.	7 N.
Munosius[b]	Ins. Carpa	15 E.	24 S.
Clavius See Tab. II.	Desertum Hevila	16 E.	60 S.
Rheticus	Pars Lacus Herculei	16 E.	5 N.
Anaxagoras[c]	Pars mont. hyperbor.	17 E.	78 N.
Pytheas	Ins. Sardinia	19 E.	21 N.
Copernicus[d]	M. Ætna	19 E.	9 N.
Junctinus		19 E.	6 S.
Molerius	Insula Zachintus	20 E.	2 S.
Philolaus		20 E.	72 N.
Guilhelmus Hassiae	M. Horeb	20 E.	44 S.
Bullialdus[f] See Tab. II.	Insula Creta	21 E.	21 S.
Longomantanus[g]	M. Anna	22 E.	51 S.
Rheinhold	M. Neptunius	23 E.	3 N.
Blancanus	Desertum Raphidim	25 E.	65 S.
Rothmann	Mons Prophetarum	25 E.	40 S.
Cychus[h]	Ins. Didymae	25 E.	36 S.
Campanus[i]	Ins. Letoa	27 E.	29 S.
Capuanus	Regio Cassiotis	28 E.	33 S.
Landsberg[k]	Ins. Maltha	28 E.	2 S.
Helicon	Ins. Erroris	28 E.	41 N.
Hortensius[l]		29 E.	6 N.
Milichius		29 E.	8 N.
Scheiner[m]	Desertum Raphidim	29 E.	60 S.
Origanus	M. Athos	30 E.	6 S.
Morinus	Fretum Sirbonicum	32 E.	16 S.
Cusanus		32 E.	13 N.

[z] Annular, with irregular central mountains, large and curious rocks on its west and east margin, and luminous ridges to the north of it.

[a] Annular, with central spot, and two luminous radiations from its south margin.

[b] Remarkable annular spot, with three large and three small marginal cavities, two large central cavities, and two small ones.

[c] Large and annular, with a high margin on its west side.

[d] Annular, with a central mountain, and broad margin, very luminous all round, with numerous rocks and mountains scattered on the N.E. of it. [e] Annular spot.

[f] Annular, with high central mountain, and three deep cavities south of it.

[g] Annular spot, with a large rock on its north margin, and several on its south-west margin. Numerous radiations seem to issue from this spot.

[h] Annular cavity, with small spot on its east margin. There is an annular spot to the south of it, a small deep cavity in high ground to the north of it, and two cavities on the margin of a half-formed spot to the west of it.

[i] Annular, with central rock.

[k] Annular spot, with a central mountain. Two radiations extend from it to Rheinhold.

[l] Annular, with a luminous radiation passing south of it, and another opening from its west margin.

[m] Annular, with central cavity, marginal cavities, and cavities without its margin.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius	Longitude.	Longitude.
Anaximander		33 E.	72 N.
Casatus[n]		35 E.	73 S.
Hainzelius		36 E.	44 S.
Herigonius		36 E.	16 S
Bayer		37 E.	50 S.
Bessarion		38 E.	16 N.
Heraclides[o]		35 E.	41 N.
Kepler	Loca Paludosa	38 E.	7 N.
Gassendus[p]	M. Cataractes	39 E.	19 S.
Deriennes	Ins. Lea	40 E.	13 S.
Diophantus		42 E.	35 N.
Schiller	Lacus Meridionalis	45 E.	53 S.
Aristarchus	M. Porphyrites	48 E.	24 N.
Bettinus[q]	M. Hajalon	49 E.	64 S.
Harpalus[r]		49 E.	57 N.
Kircher[s]	Vallis Hajalon	49 E.	68 S.
Mersenius[t]		50 E.	24 S.
Zupus	M. Ajax	50 E.	20 S.
Billy		50 E.	13 S.
Christmann		51 E.	43 S.
Fontana	M. Sacer	51 E.	16 S.
Reiner[u]		52 E.	9 N.
Linnemann	M. Thambes	55 E.	0
Zucchius[x]		56 E.	63 S.
Phocylides	M. Tadnos	58 E.	51 S.
Galilæus	M. Audus	58 E.	9 N.
Marius[y]	Pars montis Germanicani	58 E.	12 N.
Vieta	Ad montem Casium	61 E.	29 S.
Seleucus[z]	M. Pentadactylus	62 E.	22 N.
Sirsalis		62 E.	14 S.
Byrgius		64 E.	27 S.
Eustachius		65 E.	12 S.
Cruger	Fontes amari	66 E.	17 S.
Cavalerius	M. Pherme	66 E.	3 N.
Hevelius		67 E.	1 S.
Schikard	M. Troicus.	68 E.	49 S.

[n] Long cavity, with central mountains, and three luminous ridges beyond its east margin. [o] High projecting promontory, with high rock.

[p] Annular, with numerous rocks south of its centre, and two annular spots on its north margin. It has a triple rock on its centre, and high irregular ground and ridges on its west and east margin. [q] Annular cavity, with central rock.

[r] Deep and annular cavity. [s] Annular cavity.

[t] Annular cavity, containing a large annular spot. It has a small cavity on its south margin, two annular spots north-west of it, and four south-west of it.

[u] Deep and annular. Ridges south of it, and numerous rocks to the north.

[x] Annular cavity, with central rock.

[y] Deep and annular, with a half-formed annular spot on its south-east, ridges south of it, and high ground north of it.

[z] Shallow and annular, with central spot. Two luminous ridges pass from it to Cardanus, one of them touching the western margin of Seleucus.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Grimaldus	Palus Maræotis	68 E.	5 S.
Pythagoras[a]	Ad Sinum hyperboreum	69 E.	63 N.
Anaximenes		69 E.	74 N.
Eichstadius	Mons Acabe	70 E.	22 S.
Cardanus[b]		70 E.	16 N.
Oenopides		71 E.	55 N.
Ricciolus	Stagnum Miris	72 E.	3 S.
Rocca		75 E.	11 S.
Bartolus		82 E.	67 S.
Cleostratus		88 E.	59 N.
Xenophanes		90 E.	52 N.

[a] Large annular spot, with annular cavity.
[b] Deeply annular, with small annular spots south-east of it.

Table II. Containing the Longitude and Latitude of 89 Lunar Spots, as determined by Tobias Mayer

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Seneca[a]	Mons Alaunus	77 26 W.	25 29 N.
Mercurius falsus[b]		76 20 W.	35 2 N.
Mercurius	Lacus hyperboreus inferior	65 27 W.	45 21 N.
Langrenus	Insula major	62 30 W.	7 31 S.
Vendelinus		62 11 W	16 46 S.
Furnerius[c]	Pars montis Paropamisi	58 10 W.	35 34 S.
Cleomedes[d]	Pars montium Riphaeorum	57 50 W.	27 48 N.
Petavius[e]	Petra Sogdiana	57 40 W.	25 17 S.
Stevinus[f]	Pars montis Paropamisi	56 21 W.	29 26 S.
Endymion	Lacus hyperboreus superior	56 12 W.	51 10 N.
Snellius[g]	M. Paropamisus	53 45 W.	33 31 S.
Taruntius	Sinus Phasianus	17 10 W.	4 56 N.
Atlas[h]	Pars M. M. Macrocemniorum	17 0 W.	17 11 N.
Proclus	M. Corax	16 59 W.	15 18 N
Goclenius	M. Caucasus	45 35 W.	9 26 S.
Hercules[h]	Pars M. M. Macrocemniorum	41 13 W.	48 58 [illegible]
Censorinus	Pars M. Hercules	32 45 W.	0 6 S.

[a] Annular, with cavity on its east margin.
[b] Large and irregularly annular, with a pointed southern margin, two large central rocks, and two smaller ones; the two largest sometimes appear as one ridge, joining the western margin. [c] Singular appearance on its north margin.
[d] Annular, with three central rocks.
[e] Long and deep chasm on its west margin; rocks north of it; annular spot, with central mountain north-east of it.
[f] Annular, with large and small annular spot on its north-east margin.
[g] Annular, with central rock, and numerous annular spots east of it.
[h] Annular, with central mountain

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Fracastorius[i]	Lacus Thospitis	32 31 w	21 22 s.
Piccolominius	Pars M. M. Sogdianorum	30 30 w	27 53 s.
Possidonius	Insula Macra	29 35 w.	32 44 N.
Vitruvius	Apollonia major	29 26 w.	17 17 N.
Theophilus	Pars M. Moschi	26 38 w.	11 25 s.
Cyrillus	Pars M. Moschi	24 35 w.	13 3 s.
Plinius[l]	Promont. Archerusia	24 16 w.	15 44 N.
Catharina	Pars M. Moschi	23 36 w.	17 8 s.
Dyonysius[m]	Pars M. Hormini	17 17 w.	2 55 N.
Aristoteles	M. Serrorum	17 10 w.	50 50 N.
Eudoxus	M. Carpathes	16 24 w.	44 39 N.
Menelaus[n]	Byzantium	16 5 w.	16 25 N.
Calippus	M Aemus	13 48 w.	40 37 N.
Maurolycus		13 11 w.	40 41 s.
Abulfeda	Pars M. Antitauri	12 42 w.	13 17 s.
Manilius[o]	Insula Besbicus	9 2 w.	14 34 N.
Apianus	Pars Anti-Libani	7 5 w.	26 41 s.
Stoeflerus	M Calchastan	6 9 w.	39 52 s
Aliacensis[p]	Pars Anti-Libani	4 1 w.	29 18 s.
Weinerus[q]	Pars Anti-Libani	3 45 w.	27 53 s.
Fernelius	Pars M. Hermo	3 32 w.	33 25 s.
Hipparchus[r]	M Olympus	3 25 w.	5 53 s.
Albategnius	M Didymus	2 48 w.	10 30 s.
Aristillus[s]	M Ligustinus	2 33 w.	33 43 N.
Autolycus[t]	M Montuniates	2 31 w.	29 46 N.
Waltherus[u]	M Tabor	0 10 w.	31 40 s.
Regiomontanus[x]	Pars M. Libanon	0 33 E.	26 44 s.
Purbachius[y]	Pars M. Libanon	1 43 E.	23 53 s.
Archimedes[z]	M. Argentarius	1 45 E.	29 17: N.
Ptolemaeus[a]	M. Sipylus	3 11 E.	8 57: s.
Arzachel[b]	M Cragus	3 20 E.	17 7 s.
Alphonsus Rex[c]	M. Masicytus	3 30 E.	12 37 s.
Orontius	M Hermo	4 9 E.	39 52 s.
Maginus	M. Seir	5 12 E.	50 34 s.

[i] Large hollow, with cavities south of it.

[k] Between Menelaus and Pliny, stretching south. A strange ridge of rough and luminous ground.

[l] Annular, with two central mountains.

[m] High rocks, and a high annular mountain between Calippus and Theaetetus

[n] With central mountain, and high rock on its south-east.

[o] Annular, with central rock.

[p] Cavity in the south margin.

[q] With central mountain.

[r] Annular, with small central rock.

[s] Deep and annular, with central rock.

[t] Large and deep, with central spot.

[u] Irregular, with central rock.

[x] Annular, and containing two small rocks.

[y] Annular, and containing three small rocks.

[z] Large and deep, with high margin.

[a] Large spot, with irregular margin of different heights.

[b] Chasms and pits on its margin; chasms north of it.

[c] Deep cavity, with central rock south-east of it. Alphonsus is irregular, with a central rock.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Alpetragius	Promont. Ænarium	5 49 E.	14 58 S.
Plato[d]	Lacus niger major	9 12 E.	51 14 N.
Tycho	M. Sinai	10 43 E.	43 0 S.
Eratosthenes	Insula Vulcania	12 1 E.	14 39 N.
Timocharis	Insula Corsica	12 3 E.	26 33 N.
Pitatus[e]	Mare mortuum	13 32 E.	30 8 S.
Stadius	Pars lacus Herculei	14 18 E.	4 58 N.
Clavius[f]	Desertum Hevila	14 52 E.	57 56 S.
Dominicus Maria	Pars Lacus Herculei	15 43 E.	6 51 N.
Pytheas 2		16 5 E.	19 15 N.
Landsbergius[g]	Insula Malta	16 49 E.	1 1 S.
Rheticus	Pars Lacus Herculei	17 40 E.	4 20 N.
Copernicus[g]	M. Ætna	19 56 E.	9 41 N.
Longomantanus[h]	M. Annae	20 0 E.	50 0 S.
Pytheas 1[i]	Insula Sardinia	20 30 E.	20 43 N.
Gulielmus Hass. Landg.	M. Horeb	20 50 E.	43 2 S.
Bullialdus[k]	Insula Creta	21 53 E.	20 30 S.
Blancanus	Desertum Raphidim	22 14 E.	62 56 S.
Reinhold	M. Neptunus	22 31 E.	2 31 N.
Heraclides falsus[l]		25 30 E.	46 46 N.
Scheinerus	Pars vallis Hajalon	28 4 E.	59 30 S.
Heraclides verus[m]		32 56 E.	40 39 N.
	Sinus Syrticus	37 43 E.	3 22 N.
Kepler	Loca paludosa	37 45 E.	8 4 N.
Gassendus[n]	M. Cataractes	39 30 E.	17 20 S.
Harpalus[o]	Insula Sinus hyperb.	41 7 E.	51 33 N.
Aristarchus	M. Porphyrites	47 2 E.	23 40 N.
Merrsenius	M. Ajax	48 49 E.	24 14 S.
Marius	M. Germanicianus	50 0 E.	11 55 N.
Schickhardus	M. Troicus	52 54 E.	45 15 S.
Galilæus	M. Audus	53 43 E.	7 47 N.
Phocilides	M. Tadnos	58 36 E.	54 12 S.
Pythagoras[q]	Ad sinum hyperboreum	59 25 E.	62 52 N.

[d] *Newton*, contiguous to its south margin, appears to be the remains of a large annular spot, like Plato. The high mountain Pico is one of the remains of its margin.

[e] Half-formed annular spot, with central rock, several marginal cavities, and a cavity communicating with it on the north-east.

[f] The south marginal spot of Clavius has a central mountain in it, and there is a high mountain on its north margin.

[g] Annular, with central mountain. [h] Numerous radiations from it.

[i] Remarkable ridges and streaks to the of Pytheas.

[k] A long ridge runs from its south margin, across one of the small cavities south of it, to the half-formed spot west of Cichus.

[l] High promontory, rising from the plain of the Sinus Iridum.

[m] High and irregular promontory, with ridges on its south-east.

[n] Triple rock in its centre. [o] Deep and annular cavity.

[p] Deep cavity, with high rocks, and two cavities E. of it, and a radiation opening from its S. E. margin. It is the most luminous part of the full Moon.

[q] Annular, with annular cavity.

Names of the Spots according to Ricciolus.	Names of the Spots according to Hevelius.	Longitude.	Latitude.
Seleucus[r]	M. Pentadactylus	62 40 E.	20 50 N.
Grimaldus[s]	Palus Maraeotis	67 30 E.	5 5 S.
Cavalerius[t]	Pars M. Pherme	67 39 E.	5 43 N.
Hevelius[u]	Pars M. Pherme	68 13 E	2 10 N.
Ricciolus[x]	Stagnum Miris	75 10 E.	2 43 S.

[r] Shallow and angular, with central rock.
[s] Irregularly annular, with broken margin.
[t] Annular, and in contact with Hevelius.
[u] Remarkable spot, containing a central body like an egg, broken at its N. end, and a small cavity Broken rocks E. of it, and a singular appearance W. of it.
[x] Irregularly annular, with an indented broken margin to the south, dark spots west of it, and a dark spot within it.

TABLE III. Table of the Names which have been given to the anonymous Lunar Spots by M. Schroeter, with their Positions, as determined by the Editor, from a comparison of Schroeter's Plates with Mayer's Engraving of the Moon, and his Table of the Lunar Spots.

Names of the Spots.	Longitude.	Latitude.	General Situation.
De La Caille[a]	0° 15′ W.	21° 5′ S.	West of Purbachius
Mont Blanc[b]	0 20 W.	16 N.	Between Cassini and Newton
Huygens[c]	0 50 W.	22 20 N.	South of Archimedes
Blanchinus[d]	1 30 W.	22 55 S.	West of Purbachius, and south of De la Caille
Wolff[e]	1 50 W.	29 52 N.	North of Eratosthenes
Bradley[f]	2 0 W.	2[illegible] 50 N.	North-east of Huygens
Cassini[g]	3 15 W.	39 57 N.	North of Aristillus.
Hadley[h]	6 W	26 50 N	North-east of Bradley
Kirch[i]	9 8 W.	30 20 N.	North of Archimedes
Higinus[k]	8 W	9 N.	S. E. by S. of Manilius
Godin[l]	10 W.	3 N.	South of Agrippa
Jr. Chr. Mayer[m]	10 W.	56 20 N.	North-east of Aristotle
Christ. Mayer[n]	9 W.	56 N.	South of the preceding
F. R. Architas[o]	10 W	54 N.	South-east of Aristotle, and south of the preceding

[a] Annular, and bordered on N. and W. with several annular spots.
[b] High rock. [c] High rock in the Appenines.
[d] Shallow, but high and irregular in the west side
[e] Elliptical insulated rock. [f] High rock in the Appenines.
[g] Annular, and enclosing other two annular cavities.
[h] High rock in the Appenines. [i] Insulated rock. [k] Irregular rock
[l] Annular spot, with central eminence. [m] Irregularly annular.
[n] Annular. [o] Annular.

Names of the Spots.	Longitude.	Latitude.	General Situation.
Boscovich[p]	11° 50′ W.	15° N.	Between Manilius and Menelaus.
Silberschlag[q]	11 55 W.	11 N.	South of Boscovich, and stretching from north-east to south-west
Taquet[r]	19 5 W.	16 30 N.	Between Pliny and Menelaus.
Maraldi[s]	31 24 W.	17 50 N	West of Vitruvius.
Roemer[t]	31 30 W.	21 30 N.	North of Maraldi.
Chr. Gaertner[u]	32 W.	57 N.	N. W. by W. of Aristotle.
Democritus[x]	35 W	60 40 N.	N W. of Aristotle
Chris. Arnold[y]	35 W	63 N	N. N. W. of Aristotle
Picard[z]	53 W.	14 N	South-west of the centre of the Crisian sea
Palitsch[a]	57 W	3 S.	North of Furnerius.
Bernouilli[b]	58 10 W	28 18 N	South-west of Geminus.
Hooke[c]	58 15 W	29 18 N.	East of southern Cepheus
Math. Hase[d]	60 5 W	[illegible]0 S	South of Petavius
Eimart[e]	66 W	[illegible] N	N E. coast of the Crisian sea
Auzout[f]	68 W	12 N	South coast of the Crisian sea
Condorcet[g]	68 W	12 N	West coast of the Crisian sea
Alhazen[h]	69 W	19 N	South-west coast of the Crisian sea
D'Alembert Mountains[i]	On Moon's E limb	From 2 13 S to 6 S	East of Grimaldus and Ricciolus
Wargentin[k]	59 E	[illegible]0 S	East of the straits which separate Phocylides and Schickardus, in contact with the latter, and nearly with the former
Hell[l]	2 45 E	31 5 S	West of Anaxagoras
Jac. Cassini[m]	7 E	67 S	East of Regiomontanus
Sasserides[n]	9 E	39 S	North-west of Tycho
Newton[o]	9 8 E	[illegible]0 20 S	South of Plato
Pico[p]	9 20 E	50 S	On the south margin of Newton
Lexell[q]	10 E	69 S	South of Anaxagoras
Thomas Street[r]	10 50 E	47 50 S	Between Maginus and Tycho
Bern de Font[s]	11 E.	61 N	On the southern margin of Cassini

[p] Shallow, and irregularly annular
[q] Long and shallow spot [r] Small annular spot [s] Shallow and annular.
[t] Annular, with central eminence. [u] Small, annular, and shallow
[x] Annular [y] Annular and shallow [z] Annular.
[a] Enclosed shallow [b] Annular [c] Irregularly annular
[d] Shallow and annular, with a central eminence [e] Annular
[f] Shallow and annular [g] Annular. [h] Annular
[i] These high mountains project distinctly beyond the defined limb of the Moon
[k] Annular and shallow. [l] Long and irregular [m] Deep irregular cavity
[n] Annular. [o] Shallow and annular. [p] A lofty pointed rock
[q] Annular, with a lateral eminence
[r] Annular, with an annular spot on its east and west margin
[s] Annular, with central eminence

Names of the Spots.	Longitude.	Latitude.	General Situation.
Robert Smith[t]	15° E.	44 10 S.	South of Wing, and nearly touching it
Heinsius[u]	16 E.	35 S.	North-east of Tycho
Wurzelbauer[x]	16 5 E.	32 S.	South-east of Pitatus, and east of Gauricus
Cichus[y]	21 5 E.	31 S.	East of Pitatus
Helicon 1[z]	21 E.	40 N.	S. W. by S. of Heraclides Falsus
Kies[a]	22 E.	26 S.	Between Cichus and Bullialdus, and equidistant from them
Helicon 2[b]	22 30 E.	40 N.	East of Helicon 1
Lambert[c]			North of Pytheas
Condamine[d]	25 25 E.	18 55 N.	North of Heraclides Falsus
Maupertuis[d]	25 30 E.	47 45 N.	Between Heraclides Falsus and Condamine
Lubinietzki	26 E.	18 30 S.	N. E. by E. of Bullialdus
Mercator[f]	26 50 E.	29 S.	S. S. W. of Campanus, between it and Cichus
Campanus[g]	28 E.	27 S.	S. E. of Bullialdus
Mayer[h]	28 5 E.	16 8 N.	N. E. of Bullialdus
De Lisle[i]	29 E.	22 55 N.	North of Euler
De la Hire[i]			
Rost[i]	[illegible]1 E.	58 S.	Between Schiller and Scheiner
Blanchini[l]	[illegible]4 50 E.	19 N.	Between Maupertuis & Scharpius
Scharpius[k]	58 20 E.	15 55 N.	N. E. of Heraclides
Vitello[l]	[illegible]8 55 E.	29 S.	Twelve degrees S. of Gassendus
Horrebow[m]	40 E.	62 N.	N. W. of Pythagoras
Marian[n]	10 55 E.	10 N.	E. of Heraclides
Louville[o]	12 50 E.	13 N.	North of Marian
Doppelmayer[p]	11 50 E.	28 S.	Between Mersennus and Vitello, N. W. of Vitello
Vinc. Wing[q]	12 30 E.	16 S.	South of Heinsius
Weigel[r]	16 E.	59 50 S.	S. E. by E. of Rost.

[t] Annular. [u] Annular, with another annular spot on its south margin.
[x] Annular, with *four* long central eminences, stretching north and south.
[y] Deep and annular, with high margin and three annular spots towards the west.
[z] Annular and insulated.
[a] Annular and shallow, with two high mountains in its margin.
[b] Annular and insulated.
[c] Annular, with singular ridges, and a volcano to the north-east of it.
[d] Shallow and annular.
[e] Two shallow annular spots, with two rocks N. E. of them.
[f] Annular and shallow, with irregular high ground in its S. margin.
[g] Annular, with a central eminence.
[h] Annular, with another annular spot, and rough ground in its W. margin.
[i] Annular. [k] Annular and deep. [l] Annular, with central eminence.
[m] Annular, and connected with Anaximander, with a rectangular row of spots.
[n] Annular. [o] Annular and shallow, with a long ridge from its N. margin.
[p] Annular and very shallow, with a central eminence, and a spot on each side of this eminence. [q] Annular and shallow. [r] Double annular spot.

Names of the Spots.	Longitude.			Latitude.			General Situation.
Wilson[s]	48°		E.	70°		S.	S. E. of Scheiner
Reinerus[s]	52		E.	10	50	N.	S. E. of Marius
Pythagoras[t]	53	30	E.	56	50	N.	N. E. of Harpalus
Jac. Herman[u]	57		E.	8		N.	S. E. of Reinerus
Pythagoras N.[x]	60		E.	63		N.	S. E. of Pythagoras, touching it
Pythagoras E.[y]	60		E	55		N.	N. E. of Pythagoras, touching it
Briggs[z]	63		E.	26	30	N.	North of Seleucus
Pingrè[a]	63		E.	60		S.	North of Bailly
Lichtenberg[b]	65		E	24		S.	E. of Briggs and Seleucus
Bailly[c]			E.			S.	E. of Bettinus, Zucchius, and Kircher .
Hausen[d]			E.			S.	East of Bailly
Abr. Goth[e] } Kaestner }			E.			S.	East of Lichtenberg
Napier[f]			E.			S.	North of Kaestner
Segner[g]	70		E.	7		S.	N. of Zucchius, and touching it
G. Wolff. Krafft[h]	72		E	28		N.	South-east of Seleucus, and N. of Cardanus
Le Gentil[i]	75		E.	75		S.	South of Bailly
Gruemberger[k]			E.			S	Between Clavius and Moretus
Short[l]			E.			S.	S. of Moretus, and touching it

[s] Annular.
[t] Annular and shallow, with a deep annular spot on its W. margin.
[u] Annular, with a long ridge on its N. margin
[x] Annular, with central eminence. [y] Annular. [z] Annular and shallow.
[a] Annular, with a long ridge from its northern margin.
[b] A very long shallow spot, stretching from N. to S. Irregularly annular.
[c] Long shallow spot, with several annular ones within it.
[d] Extremely elliptical, with two bright eminences in the centre.
[e] A very long annular spot, with a large central ridge.
[f] Annular, with two central eminences.
[g] Annular and shallow, with long ridges from its north margin.
[h] Annular. [i] Annular, with central eminence.
[k] Annular, with central cavity. [l] Annular, with central eminence.

Table IV. Containing the Names and Positions of the larger and more remarkable Spots, which were supposed to be Seas by Ricciolus and Hevelius.

Names according to Ricciolus.	Names according to Hevelius.	General Position.
Mare Crisium, Crisian Sea[a]	*P. Mæotis*, Lake of Mæotis	57° W. 16° N.
M. Fœcunditatis, Sea of Fertility[b]	*Mare Caspium*, Caspian Sea	50 W. 5 S.
Mare Nectaris, Sea of Nectar	*Sin. Athen. et Sin. exter. Ponti*	35 W. 15 S.
M. Tranquillitatis, Sea of Tranquillity[c]	*Pontus Euxinus*, Euxine Sea	30 W. 5 N.
M. Serenitatis, S. of Serenity[d]	*Pontus Euxinus*, Euxine Sea	20 W. 30 N.
Lacus Somniorum, Lake of Dreams[e]	*Sinus Cercinetis*	30 W. 37 N.
L. Mortis, Lake of Death[f]	*Montes Peuce*	29 W. 48 N.
Palus Somnii, Lake of Sleep[g]	*Lacus Corocondametis*	41 W. 14 N.
Mare Frigoris, Sea of Cold	*Mare Hyperboreum*, Hyperborean Sea	From 30 E. to 40 W. 55 N.
M. Vaporum, Sea of Vapours	*Propontis*	6 W. 10 N.
Sinus Æstuum, Bay of Tides[h]	*M. Adriaticum*, Adriatic Sea	7 E. 2 N.
M. Nubium, Sea of Clouds[i]	*Mare Pamphylium*, Pamphylian Sea	15 E. 20 S.
M. Humorum, S. of Moisture[k]	*Sin. Sidon. et M. Ægyptiac.*	40 E. 25 S.
Sinus Epidemiarum, Bay of Epidemics	*Insula Didymae*, Island of Didyma	30 E. 22 S.
Oceanus Procellarum, Ocean of Storms[l]	*M. Eoum, et M. Medit. Pars*, Eastern Sea, and part of the Mediterranean	In equat. crossed by parallels, 22 32 50 E.
M. Imbrium, Sea of Showers	*Mare Med. Pars Septent.*	20 E. 30 N.
S. Iridum, Bay of Rainbows[m]	*S. Apollinis*, Bay of Apollo	31 E. 44 N.
Sinus Roris, Bay of Dew[n]	*S. Hyperboreus*, North. Bay	45 E. 50 N
Terra Pruinæ, Land of Hoar frost		27 E. 49 N.
Terra Siccitatis, Land of Drought	The last five names have been introduced by Schroeter.	40 E. 62 N.
Palus Putredinis, Land of Putrefaction[o]		0 25 N.
P. Nebularum, Lake of Fogs[p]		2 W. 31 N.
T. Grandinis, Land of Hail[q]		0 50 N.

[a] High in the middle, with a ridge running from its E. to N. margin.
[b] Long spot, stretching from N. to S with rocks and cavities interspersed.
[c] The north-east part of it is covered with annular spots
[d] Covered with gentle elevations, and with low ridges, which appear like streaks of light at full moon. [e] Long irregular blackish spot, N. W. of *M. Serenitatis*.
[f] Small faint black spot, with some annular spots.
[g] A pale spot, containing several small annular ones
[h] Small black spots. [i] Interspersed with small rocks and cavities.
[k] Covered with rocks and ridges on its N. E. extremity.
[l] This name is given to all the large spots between 10° south and 20° north, and lying to the east of the parallel of 20° east. [m] Small semicircular valley.
[n] Containing Harpalus, &c. [o] South of Autolycus.
[p] Between Autolycus and Aristillus.
[q] Lying between Plato and Cassini, and covered with numerous rocks.

Having thus given a full tabular view of the names, positions, and general appearance of the mountains and spots on the Moon's surface, we shall now proceed to give an account of the different phenomena which may be discovered by a minute examination of her disc.

Astronomers have not been content with merely inspecting the surface of the Moon, they have even attempted to measure the height of the mountains, and the depth of her cavities; and though on this point there is a difference of opinion, greater than might have been expected, the results are still highly curious and interesting.

Ricciolus's method of measuring the lunar mountains. Plate IV. Fig. 2.

Ricciolus proposed to measure the mountains of the Moon, when she was in quadrature with the Sun, or when the half of her disc was illuminated. He supposed D A E to be the side of the Moon that was turned to the Earth, or the circle D A E, to be a section of the Moon perpendicular to the boundary of light and darkness, and D A the half of her hemisphere, that was illuminated by the Sun. Then, if M be a mountain placed in the dark part of her disc, and viewed by an observer on the Earth at O, it is obvious, that whenever its summit becomes visible to the spectator, it must be illuminated by a ray of the Sun, S M A, which is perpendicular to B A, the radius drawn from the centre of the Moon, to the boundary of light and darkness. If we then measure, with a micrometer, the angle subtended by the line M A, the space between the luminous vertex of the mountain, and the enlightened part of the Moon's disc, we shall have the two sides A M, A B, of the right angled triangle A M B to find the third side B M, and consequently, C M, the height of the mountain, or the excess of B M above B C. By the 47th of the first book of Euclid, we have $AM^2+AB^2=BM^2$. Hence, $BM=\sqrt{AM^2+AB^2}$, but $BM=CM+BC$; consequently, $CM+BC=\sqrt{AM^2+AB^2}$, and $CM=\sqrt{AM^2+AB^2}-BC$.

Dr. Herschel's method. Plate IV. Fig. 3.

As this method is applicable only when the Moon is dichotomised, it is necessary to have a more general method of ascertaining the altitude of her mountains. This defect has been supplied by the following simple and ingenious method, suggested by Dr. Herschel, and applicable in every part of the Moon's orbit. Let D A E be the hemisphere of the Moon which is

turned to the Earth, and D A the visible portion of the enlightened hemisphere F D A. Let M be a mountain, viewed by an observer on the Earth at O; then it is obvious, that if we measure with a micrometer the distance between the summit M of the mountain, and the illuminated disc at A, we shall have the angle subtended by A *r*, from which, it is easy to ascertain the length of A M, in parts of the Moon's radius. Produce O M to *n*. Draw A *m* parallel to O *n*, and let A *r* be parallel to *m n*, it is obvious that the angle S M *n*, or its equal A B D, is the elongation of the Moon from the Sun, and that A *m* is the sine of the angle of elongation. Now, the right angled triangles A M *r*, and A B *m*, are similar, from the equality of the angles at M and B; therefore, we have $A\,m : A\,B = A\,r : A\,M$. Hence, $A\,M + A\,m = A\,B + A\,r$ and $A\,M = \frac{A\,B + A\,r}{A\,m}$, that is, the distance between the enlightened summit of the mountain, and the illuminated part of the Moon's disc, is equal to the projected distance, as measured by the micrometer, divided by the sine of the Moon's elongation from the Sun, radius being unity.

Dr. Herschel, for example, found that a rock situated near the Lacus Niger of Hevelius projected 41″.56. Then to reduce this into miles we have A B in seconds : 1090 miles = A *r* in seconds : A *r* in miles, or $A\,r \text{ in miles} = \frac{1090\,A\,r}{A\,B}$ Taking A B from the Nautical Almanack for the time, it will be found that A *r*, or 41″.56 = 46.79 miles But the elongation of the Moon at that time was 93° 57½′, the sine of which is .9985. Hence $\frac{A\,r}{A\,m}$ is 46.85 miles = A M. Then, by the method of Ricciolus, the perpendicular height of the rock will be found to be about one mile.

As the points O, S, A, *r* (Fig. 3), are all supposed to be in one plane, or in the same plane with the illuminating ray S A, the distance A *r* ought always to be measured in a direction parallel to the illuminating ray, or perpendicular to the line joining the cusps of the Moon. This may be done by keeping the fixed wire of the micrometer parallel to the line joining the cusps, till the space A *r* is included between the wires. The proper position of the wire may also be found from the shadows of any adjacent eminences, which will always point out the di-

rection of the illuminating ray. If the mountain is situated within the area F *s p* A (Fig. 2), the error arising from taking the measure A *r* (Fig. 3) perpendicular to the terminator, or the elliptical boundary of the light and dark part of the Moon's disc, instead of perpendicular to the line joining the cusps, will not amount to $\frac{1}{10}$ of the whole. If the mountain is within the area F *r o* A, the error will not be $\frac{1}{20}$ of the whole; and if it is within the area F *q n* A, the error will not be one hundredth of the whole. The arches D *n*, D *o*, D *p*, or D *q*, D *r*, D *s*, are respectively 8°, 18°, 26°.

Dr. Herschel measured several of the lunar mountains with great care, and found that their height had been greatly overrated by preceding astronomers. With the exception of a few, it appeared that the general height of the mountains does not exceed half a mile. The following are some of his measurements:—

	Distance A M in miles.	Height in miles.
A rock near the Lacus Niger of Hevelius,	46.85	1.0
Antitaurus,	31.7	0.5
Mount Lipulus,	37.54	0.61
One of the Appenines, between lake Thrasimenus and the Euxine sea,	52.9	1.25
Mons Armenia, near Taurus,	38.0	0.66
Mons Leucopteria,	41.4	0.75
Mons Sacer,	64.0	1.8
Promontorium Acherusia,	22.6	0.25
The highest mountain situated near Snell or Petavius,	35.3	0.57
Mountain behind Mare Crisium,		0.5
Mountain near Aristotle,	28.53	0.37
Mons Sinopium,	56.54	1.50

The altitude of the mountains obtained by the two preceding methods is evidently not taken from the general level of the Moon's surface. When the solar rays, which illuminate the summit of the mountain, pass over high ground, which is the same thing as when the point A is above the general level of the Moon's surface, the height C M is the height above the level of the point A, and is, consequently, too small, by the quantity which A is raised above the general level of the Moon's surface. On the contrary, if there are any hollows at A, which permit the rays of the Sun to reach the vertex of the mountain sooner than they would have done had the ground at

A been level, we then get the height of the mountain from the bottom of these hollows; a result too great, by the quantity which these cavities are depressed below the Moon's surface. Both these cases, particularly the first, must frequently occur, and will require no small address in the practical astronomer, to apply the necessary corrections.

A method different from any of the preceding has been very successfully employed by M. Schroeter. He measures the projections of the shadows of the mountains, when the Sun is near their horizon, and is either about to leave them in darkness, or advance to the meridian. From the distance of the mountains from the boundary between light and darkness, we presume that he finds the altitude of the Sun above their horizon, and thus deduces the altitude of the mountains. In this way, he has measured not only the lunar mountains, but likewise the depth of her immense cavities; and it appears from his observations, which we shall give at some length, that the mountains of the Moon are considerably higher than those on our own globe.

In the following Tables, we shall present the reader with the various measurements of Schroeter, relative to the height, and the breadth of the base of insulated mountains, central mountains, annular mountains, the heads of annular mountains, and stratified mountains, and likewise with the depth and breadth of the lunar cavities.

TABLE I. Containing the Height and Breadth of insulated Mountains, the Height of the Moon's Atmosphere being 1.622 English Miles, and the Height of the more dense Part, which produces Twilight, being .381 English Miles.

Ref. to Schroeter's Plates.	Names of insulated Mountains.	Height in English miles	Length of Base in Eng. miles	General Remarks.
d	Leibnitz	5.007	36.88	None of these seven mountains appear in Schroeter's plates.
e		5.013	46.10	
b		4.947	32.27	
a		4.886	23.05	
α	Deerfel	5.007	29.96	
γ		4.874	62.23	
β		4.656	27.66	
	Rook	4.886	23.05	On the Moon's eastern limb, in lat. 24° 5'.
δ		4.880	20.74	
ϑ		4.680	27.66	
p		4.571	17.29	
l		4.517	27.66	Round mountain, with lower one on its S. side.
O				
	Mountains of D'Alembert	4.517	27.66	Steep on its S. side, with hollows.
n		3.639	96.81	Long ridge, of equal height.
c		3.469	17.29	
e		3.226	12.68	d, e, f, g, h, on the same limb.
r		3.277	27.66	
a		2.313	20.74	
g		2.313	32.21	
	Huygens	4.014	11.49	Round rock in the Appennines.
	Calippus East	3.183	23.05	
K	Bradley	3.081	27.66	Round rock N. of Conon, and
L		3.277	13.83	ditto E. of Conon.
	Mont Blanc	2.654	14.98	Part of a broken ridge.
H	Hadley	2.646	11.52	
I		2.104	9.22	Rocks in the Appennines.
	Wolff	2.301	36.88	Elliptical rock, with chasm in its S. extremity.
n	In Crisian Sea	2.179	16.13	Ellipt. rock near its E. margin.
k	Near Theætetus	2.179	27.66	Large mountain, with high rock on its S. E.
ik	E. of Purbachius	2.058	11.52	Large mountain.
α	W. of Geminus	1.992	34.57	
bb	S.E. by E. of Eudoxus	1.986	18.44	Large rock, stretching from E. to W.
Z	Alp	1.955	9.22	
v		1.653	14.98	
y		1.171	13.83	

TABLE I. continued.

Ref. to Schroeter's Plates.	Names of isolated Mountains.	Height in English miles.	Length of Base in English miles.	General Remarks.
	Pico	1.816	9.22	High ins. rock, S. marg. of Newt.
r	S.E. of Eratosth.	1.810	31.57	Large mount. touching Eratos.
u	Near Plato	1.100	19.59	E. of Plato.
	Mayor Promont.	1.290	18.44	Large rock.
β	Near Mare Seren.	1.280	17.29	
	Promont. Alp.	1.145	9.22	
	Heraclides Fals.	1.110	8.07	High peak on lofty promontory.
i	Alp	1.110	16.13	
h		1.095	17.29	
d	Near Aristarchus	1.000	10.37	E. of Aristarchus.
B	Near Newton	1.332	11.52	S. of Pico, in marg. of Newton.
u	Near Theatetus	1.174	9.22	Part of ridge W. of Theatetus,
k	Alp	1.120	14.98	and S. of small annular spot.
m	In Crisian Sea	1.120	9.22	N. E. of Picard.
k	Near M. Serenit.	1.114	6.15	See Schroeter, Plate LVII.
α		1.059	5.76	
ò	Near Aristarchus	1.029	10.37	Part of high ridge N.E. of Aristarchus.
	De la Caille, in the middle	0.853	19.39	See Schroeter, Plate XXIX.
	De la Hire	0.823	10.37	Brilliant mount. like a volcano.
dd	Near Aristotle	0.799	18.44	Long narrow mountain, S. E. of Aristotle.
i	Near Eratosthen.	0.771	10.37	E. of Eratosthenes.
u	Lichtenberg	0.707	6.91	On its W. marg. E. of Seleucus.
g	Near Fontenelle	0.635	3.46	
ϑ	Near Archimides	0.611	13.83	Semicirc. ridge, S. of Archimed.
g	Near Hortensius	0.593	11.52	Large rock N.N.E. of Hortens.
A	Near Euler	0.575	4.61	S. of Euler, and nearest it.
α	Near Plato	0.575	5.76	N. of Mont Blanc.
m	Near Thebit	0.393	9.22	Semicirc. ridge E. of Thebit.
i	Near Euler	0.381	8.07	S.W. of mount. A, and N. of B.
f	Near Thebit	0.375	11.52	S. E. of Thebit.
g	Kies	0.339	4.61	Mountains on the S. E. margin
h		0.248	3.46	of Kies.
	Nr Doppelmayer	0.127	8.07	
v	Near Bullialdus	0.127	3.46	North of Bullialdus.
b	Near Hermann.	0.127	5.76	
	Nr Doppelmayer	0.025	10.76	

TABLE II. Containing the Height of Central Mountains, and the Length of their Base.

Ref. to Schroeter's Plates	Names of the central Mountains	Height in English miles	Length of Base in Eng. miles	General Remarks
w	Arzachel	1.459	10.37	High and long rock, with peak higher than the rest, whose shadow is like a black spot in the rock.
C	Alphonsus	1.332	5.76	In annular cavity S. of Alphonsus.
B	Pythagoras	1.211	16.13	See Schroeter, Plate XXVI.
	Albategnius	1.150	10.37	
	Walter	0.999	9.22	Very irregular hill, with two arms stretching north and west, and small annular cavity near each arm.
x	Arzachel	0.623	10.37	Small annular mountain.
γ	Alphonsus	0.623	16.13	Small round rock.
	Vitello	0.357	6.15	See Schroeter, Plate LIV.
	Gassendi	0.278	13.83	This mountain has three tops, one of which appears like a bright spot in the shadow of the other, when the sun is in its horizon. See Schroeter, plate LIV.
e fig. 1	Doppelmayer	0.208	11.52	
a	Tycho	0.690	10.37	Near the west end of the annular cavity. See Schroeter, Plate LV

The central mountains, whose height and magnitude are given in the preceding Table, are those which are placed in the centre of the spots or cavities that are surrounded with annular mountains. Sometimes these mountains are found towards one side of the cavity; but, in general, their position is exactly central. The references in the Table to Schroeter's Plates will be of advantage to those who wish to examine the subject with greater care.

TABLE III. Containing the Heights of the Heads of Annular Mountains, and the Length of their Base.

Ref. to Schroeter's Plates	Names of the Mountains.	Height in English miles	Length of Base in Eng. miles
γ	Clavius	3.282	10.37
∂	Clavius	2.058	13.83
b	Ptolemy	1.601	36.88
B	Clavius	1.423	6.91
x	Alphonsus	1.180	9.22
n	Walther	0.968	23.05
e	Ptolemy	0.927	23.05
d	Ptolemy	0.817	36.88
E 2.	Alphonsus	0.732	9.22
L 1.	Alphonsus	0.726	9.22
	Bullialdus	0.641	50.49
	Bullialdus	0.563	50.49
	Hermann	0.172	6.91
	De la Caille	2.198	27.66
	Eratosthenes	1.852	34.57
	Plato	1.450 } 1.410 }	69.15
	Archimedes	1.332	59.93
	Cassini	0.835 } 0.756 }	36.88

TABLE IV. Containing the Heights of Annular Mountains, with the length of their Base.

Refer. to Schroeter's Plates	Names of the Annular Mountains.	Height in English Miles	Length of their Base in English Miles
	Tycho East	2.016	59.93
A	Clavius	1.429	36.88
C	Clavius East	1.429	52.13
	Aristillus	1.362	64.10
	Autolycus	1.332	28.81
	Clavius	1.211	27.66
t	Near Theatetus	1.192	10.37
l	Eratosthenes	1.114	33.42
	In the Crisian Sea	0.932	9.22
	Archimedes	0.902	59.93
	Vitello East	0.835	27.66
	Gassendi West	0.690	71.45
B	Near Archimedes	0.708	9.22
	Landsberg	0.702	32.27
	Theatetus	0.599	21.90
	Near Alpetragius	0.538	9.22
	Plato	0.538	69.15
l	Near Aristarchus	0.538	9.22
	In Cassini	0.538	9.22
	Timocharis	{ 0.623 0.520 }	23.05
f	Near Newton	0.563	8.07
c	Hell	0.448	29.20
k	Mare Serenit.	0.339	11.52
a	Olbers	0.217	16.13
	Hermann	0.217	16.13
o	Near Bullialdus	0.193	16 14
q	Clavius	0.193	6.91
q	Near Marius	0.127	65.96
	Lichtenberg	0.108	6.91
n	Near Marius	0.090	unknown.
	Manilius	0.423	27.66
m	Near Aristerchus	0.399	6.15
h	Near Heraclides	0.399	9.22
d	Near Thebit	0.399	13.83
	Rheinhold	0.387	34.57
l	Near Timocharis	0.345	4.61
B	Near Copernicus	0.345	11.52
	Cassini *Alt. Med.*	0.345	36.88
	Euler	0.314	27.66
w	Near Plato	0.272	8.07
	Hortensius	0.272	13.83
	Pliny	0.248	34.57
	Near Aristillus	0.230	5.76
	Near Possidonius	0.193	6.15
•	Near the Sinus Æstuum	0.181	6.15

TABLE V. Containing the Heights of Strata of Mountains, and the Length of their Base.

Ref. to Schroeter's Plates.	Names of Mountains.	Height in English Miles.	Length of their Base in English miles.
	Near Marius	0.502	4.61
	Near Aristarchus	0.502 0.333	5.76
	Near Newton	0.260 0.169	4.61
	Near Heraclides Falsus	0.193 0.108	3.16
1*mum.*	Mar. Seren.	0.181 0.108	6.15
	Near Thebit	0.096	2.30
2*dum.*	Mar. Seren.	0.108	6.15
3*tium.*	Mar. Seren.	0.078	6.15
	Near Archimedes	0.072	5.76
	Near Marius	0.121	1.61
	Near Hermann	0.096	5.76
	Near Marius	0.084	4.61
	Near Marius	0.066	4.61
	Near Hermann	0.018	5.76
	Ibid	0.012	1.61
	Near Hermann	0.012	1.61

TABLE VI. Containing the Depth of the Lunar Cavities, and the Breadth of their Orifices.

Ref. to Schroeter's Plates.	Names of the Cavities	Depth in English miles.	Breadth of their Orifices.
	Bernouilli	3.760	16.13
A	Helicon West	2.603	18.14
	Eudoxus	2.385	10.25
	Thebit	2.361 1.974	29.96
	Pytheas	2.343	10.37
B	Helicon East	2.276	19.59
c	Thebit	2.119	11.52
	Lambert	1.900 1.515	10.37
	Theatetus	2.064	16.13
	Calippus	1.901	14.08
	Manilius	1.901 1.737	10.37
	Bianchini	1.816	27.66
	Euler	1.804	13.83
	Autolycus	1.804 1.707	18.44
	Rheinhold	1.647	20.74

TABLE IV, continued.

Ref. to Schroeter's Plates	Names of the Cavities.	Depth in English miles	Breadth of their Orifices
	Copernicus	1.816 1.610	37.95
•	Picard	1.568	13.83
I	Near Aristotle	1.562	9.22
	Menelaus	1.513 1.410	14.98
	Pliny	1.392	24.20
	Timocharis	1.410 1.332	18.44
	Landsberg	1.332	20.74
d	Near Thibet	1.126	8.07
	Aristarchus	1.108	23.05
A	Near Pliny	1.077	11.52
ζ	Near Purbachius	1.059	6.15
. F	Near Copernicus	0.987	6.15
S	Near Pliny	0.920	10.37
E	Near Regiomontanus	0.847	10.37
ϡ	Near de la Caille	0.847	10.37
e	Near Thebit	0.781	8.06
	Conon	0.678	10.37
	Tobias Mayer	0.502	16.13
Cris. Sea.	Near Picard	0.290	34.57
	Newton	3.700	43.70
	Mylius	3.112	32.27
C	Near Alphonsus	2.797	20.74
	Desplaces	2.349	18.44
	Aristillus	1.937	36.88
C	Hell	1.937	19.59
	Tycho	1.961	50.71
	Tycho	1.750	50.71
A	Walther	1.695	8.07
A	Ptolemy	1.592	20.74
	Bullialdus	1.447	27.66
	Godin	1.435	17.29
	Possidonius	1.423	6.15
h	Near Possidonius	1.350	9.22
	Marius	1.180	24.20
E	Architas	1.180	18.44
	Agrippa	1.217	21.48
F	Architas	1.126	11.52
.	Fontenelle	1.017	21.90
β	Mar. Seren.	0.999	7.65
	Aristarchus	0.762	23.05
	Cardan	0.762	27.66
	Krafft	0.635	27.66
M	Near Possidonius	0.635	3.04
q	Mar. Seren.	0.617	4.61
K	Mar. Seren.	0.508	6.13
z'	Alphonsus	0.363	8.07

It appears from the remarks contained in the preceding tables, and it may be observed with the aid of a common telescope, that the lunar surface is not only diversified with rocks and cavities, but that some parts of it are distinguished from others by their superior illumination. The dark parts of the Moon's disc are always smooth, and apparently level; while the luminous portions are elevated tracts, which either rise into high mountains, or sink into deep and extensive cavities. The general smoothness of the obscure regions naturally induced astronomers to believe that they were immense collections of water. The names given by Hevelius are founded on this opinion; and notwithstanding the discoveries which have been made on the surface of the Moon, it is still very generally maintained among modern astronomers. When we examine the Moon's disc, however, with minute attention, we find that these obscure portions are not exactly level like a fluid surface. In many of them the inequality of surface and of light is considerable; and in some parts parallel ridges are distinctly visible. The large dark spot on the Moon's western limb, which is called the *Crisian sea*, appears in general to be extremely level; but we have frequently observed, when the Moon was a little past her opposition, and when the boundary of light and darkness passed through the Crisian sea, that this bounding line, instead of being elliptical, as it would have been had the surface been fluid, was irregular, and evidently indicated that this portion of the Moon's disc was actually elevated in the middle. The light of these obscure regions, likewise, varies very much, according to the angle of illumination, or the altitude of the Sun above their horizon; and when the Moon is near her conjunction they are not much less luminous than the other parts of her disc. Now this could never happen if they were covered with water; for when a fluid surface is not ruffled by the wind, the light of the Sun, or rather the image of the Sun, could not be seen, unless when the eye of the observer was in the line of the reflected rays. It would appear, therefore, from these facts, that there is no water in the Moon, neither rivers, nor lakes, nor seas; and hence we are entitled to infer that none of those atmospherical phenomena, which arise from the existence of water in our own globe, will take place in the lunar world.

The dark parts of the Moon do not contain water.

Lunar mountains.

The strata of mountains, and the insulated hills which mark the disc of this luminary, have evidently no analogy with those in our own globe. Her mountainous scenery, however, bears a stronger resemblance to the towering sublimity, and the terrific ruggedness, of Alpine regions, than to the tamer inequalities of less elevated countries. Huge masses of rock rise at once from the plains, and raise their peaked summits to an immense height in the air, while projecting craggs spring from their rugged flanks, and threatening the valleys below, seem to bid defiance to the laws of gravitation. Around the base of these frightful eminences are strewed numerous loose and unconnected fragments, which time seems to have detached from their parent mass; and when we examine the rents and ravines which accompany the overhanging cliffs, we expect every moment that they are to be torn from their base, and that the process of destructive separation which we had only contemplated in its effects, is about to be exhibited before us in tremendous reality. The strata of lunar mountains called the Appenines, which traverse a portion of her disc from north-east to south-west, rise with a precipitous and craggy front from the level of the Mare Imbrium. In some places their perpendicular elevation is above four miles; and though they often descend to a much lower level, they present an inaccessible barrier to the north-east, while, on the south-west, they sink in gentle declivity to the plains.

Lunar caverns.

The analogy between the surface of the Earth and Moon fails in a still more remarkable degree, when we examine the circular cavities which appear in every part of her disc.* Some of these immense caverns are nearly four miles deep and forty miles in diameter. A high annular ridge, marked with lofty peaks and little cavities, generally encircles them; an insulated mountain frequently rises in their centre, and sometimes they contain smaller cavities of the same nature with themselves. These hollows are most numerous in the south-west part of the Moon; and it is from this cause that that portion of this luminary is more brilliant than any other part of her disc. The mountainous ridges which encircle the cavities, reflect the greatest quantity of light; and from their lying in every possible direction, they appear near the time of full Moon like a number of brilliant radiations, issuing from the large spot called Tycho.

Explanation of the lunar caverns.

It is difficult to explain, with any degree of probability, the formation of these immense cavities; but we cannot help thinking that our Earth would assume the same figure if all the seas and lakes were removed; and it is therefore probable that the lunar cavities are either intended for the reception of water, or that they are the beds of lakes and seas which have formerly existed in that luminary. The circumstance of there being no water in the Moon is a strong confirmation of this theory.

Volcanoes in the Moon.

The deep caverns and the broken irregular ground which appear in almost every part of the Moon's surface have induced several astronomers to believe that these inequalities are of volcanic origin. This opinion was first maintained by Dr. Hook, in his *Micographia*, and was afterwards supported by Beccaria, Lichtenberg, and Æpinus, the latter of whom published a memoir on this subject in 1781. The conjectures of these astronomers have received no small confirmation from a number of remarkable phenomena which have been seen in the dark part of the Moon in the course of the last century. During the annular eclipse of the Sun, which happened on the 24th June 1778, a very singular phenomenon was observed by Don Ulloa. Before the edge of the Sun's disc emerged from that of the Moon, he observed near the north-west limb of the Moon a bright white spot, which he imagined to be the light of the Sun shining through an opening in the Moon. This phenomenon continued about one minute and a quarter, and was noticed by three different observers. Beccaria observed a spot similar to this in 1772, and imagined that it, as well as that perceived by Ulloa, were the flames of a burning mountain. Mr. Bode of Berlin also perceived a bright spot in the dark limb of the Moon. M. de Villeneuve and M. Nouet saw a luminous point near the spot Heraclides on the 22d May 1787, and on the 13th March 1788. It resembled a small nebula, or a star of the sixth magnitude, and seemed to vary considerably in the light which it emitted. This bright spot was again seen on the 8th of May by Mechain, who thought that it was the brilliant point of the spot Aristarchus shining by the secondary light reflected from the Earth. A very brilliant spot was seen in the obscure part of the Moon on the 7th March 1794, by Mr. Wilkins of Norwich, and Mr. Stretton in London. It appeared in the north-east part of the Moon's disc,

and continued visible for nearly five minutes. Phenomena of a similar kind have been observed by Dr. Herschel. On the 4th May 1783, he perceived a luminous point in the obscure part of the Moon, and two mountains, which were formed from the 4th to the 13th May. In 1787, he perceived similar phenomena, which we shall describe in his own words.

Volcanoes discovered by Dr. Herschel.

"April 19, 1787, 10h 36′ sidereal time. I perceive," says Dr. Herschel, "three volcanoes in different places of the dark part of the new Moon. Two of them are either already nearly extinct, or otherwise in a state of going to break out; which perhaps may be decided next lunation. The third shews an actual eruption of fire, or luminous matter. I measured the distance of the crater from the northern limb of the Moon, and found it 3′ 57″.3. Its light is much brighter than the nucleus of the comet which M. Mechain discovered at Paris the 10th of this month.

"April 20, 1787, 10h 2′ sidereal time. The volcano burns with greater violence than last night. I believe its diameter cannot be less than 3″, by comparing it with that of the Georgian planet; as Jupiter was near at hand, I turned the telescope to his third satellite, and estimated the diameter of the burning part of the volcano to be equal to at least twice that of the satellite. Hence we may compute that the shining or burning matter must be above three miles in diameter. It is of an irregular round figure, and very sharply defined on the edges. The other two volcanoes are much farther towards the centre of the Moon, and resemble large pretty faint nebulæ, that are gradually much brighter in the middle; but no well defined luminous spot can be discerned in them. These three spots are plainly to be distinguished from the rest of the marks upon the Moon; for the reflection of the Sun's rays from the Earth is in its present situation sufficiently bright, with a ten feet reflector, to shew the Moon's spots, even the darkest of them; nor did I perceive any similar phenomena last lunation, though I then viewed the same places with the same instrument.

"The appearance of what I have called the actual fire, or eruption of a volcano, exactly resembled a small piece of burning charcoal, when it is covered by a very thin coat of white ashes, which frequently adhere to it when it has been some time ignited; and it had a degree of brightness about as strong

as that with which such a coal would be seen to glow in faint daylight.

"All the adjacent parts of the volcanic mountain seemed to be faintly illuminated by the eruption, and were gradually more obscure as they lay at a greater distance from the crater.

"This eruption resembled much that which I saw on the 4th of May in the year 1783; an account of which, with many remarkable particulars relating to volcanic mountains in the Moon, I shall take an early opportunity of communicating to this society. It differed, however, considerably in magnitude and brightness; for the volcano of the year 1783, though much brighter than that which is now burning, was not nearly so large in the dimensions of its eruption. The former, seen in the telescope, resembled a star of the fourth magnitude, as it appears to the natural eye; this, on the contrary, shews a visible disk of luminous matter, very different from the sparkling brightness of star-light.

Formation of craters.

The formation of craters in different parts of the Moon seems also to indicate the existence of volcanoes. With an excellent achromatic telescope, five feet long, and with an aperture of three inches and three-quarters, Dr. Olbers discovered in the Mare Crisium, between Picard and Auzout, two small craters in the grey plain, which were both wanting in Schroeter's Topographical Charts. Schroeter had frequently examined this part of the Moon with high magnifying powers, under very favourable angles of illumination, but had never perceived the slightest trace of these craters. Schroeter at last perceived the largest of them, which was uncommonly deep in proportion to its breadth, and was surrounded with a broad annular elevation of little brightness.

Plate IV. *Sup.* Fig. 4, 5, 6.

In order to convey to the reader some idea of the lunar surface, we have represented three portions of it as drawn by Schroeter, in Plate IV, *Sup.* fig 4, 5, 6. Fig. 4 is the very brilliant spot called Aristarchus, in the north-east quadrant of the Moon's surface. Fig. 5 represents the spot called Gassendi, in the south-east quadrant of the Moon, the dark edge *a b* representing the boundary between the illuminated and obscure part of her disc. Fig. 6 is the spot called Hevelius, containing an annular cavity, and a broken elevation resembling an egg.

The height of the lunar mountains, relative to those in the

Earth, Mercury, and Venus, is shewn in Fig. 7, where those in Venus appear to be highest, and those of the Earth the lowest.

Plate IV. Sup. Fig. 7.

Arguments against the existence of a lunar atmosphere.

The existence of a lunar atmosphere has long been a fertile subject of dispute among philosophers. The constant serenity of the Moon's surface, undisturbed by clouds or vapours, induced astronomers to believe that she was not surrounded with an atmosphere; and this opinion was confirmed by the brilliancy of light retained by the fixed stars and planets, when they were nearly in contact with the limb of the Moon, and when their light must have passed through her atmosphere. M. De Fouchy, in a memoir upon this subject, endeavours to shew, that the duration of eclipses and occultations ought to be diminished by means of the refractive power of the Moon's atmosphere; and if its horizontal refraction amounted to 8″, that there never could be a total eclipse of the Sun. In the eclipse of that luminary which happened in 1724, total darkness continued 2′ 16″; a circumstance which Fouchy maintains could not possibly have happened, had the Moon been encircled even with the rarest atmosphere. These arguments, however ingenious they may be, are founded upon the supposition, that the data on which his calculations are made are perfectly correct.

The appearance of the Moon's limb, in total and partial eclipses of the Sun, has suggested numerous arguments for the existence of a lunar atmosphere. In the year 1605, Keppler perceived that the Moon, in a solar eclipse, was surrounded with a luminous ring, which was most brilliant on the side nearest the Moon. The same phenomenon was observed by Wolff in the total eclipse of May 1706. Captain Stanyan, who observed the same eclipse at Bern, perceived a blood red streak of light immediately before the emersion of the Sun's limb. Fatio observed at Geneva the luminous ring round the Moon; and Dr. Scheuchzer describes the eclipse as appearing annular, in consequence of the refraction of the Sun's light by the atmosphere of the Moon. In the total eclipse of 1715, Dr Halley observed a diminution of brightness in the limb of the Sun, which was immerging before total darkness. The sharp horns of the solar crescent were blunted at their extremities during total darkness, and a ring of light encompassed the

Moon. The ring was brightest near the body of the Moon, and flashes or corruscations of light seemed to dart out on all sides from behind the Moon a little before the emersion. About two seconds preceding the emersion, a long narrow streak of dusky but strong red light seemed to colour the western limb of the Moon; but when the Sun appeared, the streak and the luminous ring instantly vanished. M. Louville observed the same phenomena; and he describes the red streak seen by Dr. Halley, as a piece of a circle of a lively red, which preceded the emersion of the Sun's limb.

In the eclipse of the Sun which happened on the 25th July 1748, when the uncovered part of the Sun resembled the Moon in her quadratures, the horns of the solar crescent were observed by Euler to be bent outwards beyond the circle, in which every other part of his disc was comprehended. When the eclipse became annular, the Sun's disc was dilated beyond the circle which formerly embraced it. This dilatation was also observed by M. Polack at Frankfort upon the Oder, and has been estimated by Euler at 25″.

From observations made upon the eclipse of the Sun in 1764, M. Du Sejour has demonstrated, that the inflexion of the rays which passed by the Moon's limb, amounted to 4½″, and must, therefore, have arisen from the refraction of her atmosphere.

In the eclipse of 1778, in which the total darkness lasted four minutes, Ulloa observed several singular appearances. The ring of light about the Moon seemed to have a rapid circular motion. This light became more dazzling as the centre of the luminaries approached, and about the middle of the eclipse its breadth was about a sixth part of the Moon's diameter. Corruscations issued from it in all directions, and the light was reddish towards the Moon, a deep yellow towards the middle, and pure white at its circumference.

Several experiments were made with the shadows of globes by Maraldi and Fouchy, to shew that the luminous ring might arise from another cause than the Moon's atmosphere. They found that a ring of light, produced by the inflexion of the passing rays, surrounded the shadows of all opaque globular bodies; and they considered this as a triumphant answer to the preceding arguments in favour of a lunar atmosphere. The answer seems to have been admitted by their opponents as satisfactory, and we do not know that its fallacy has ever been

exposed. As the phenomena of inflexion are produced merely by the surfaces of bodies, the breadth of the luminous ring, produced by the inflexion of light passing by the head of a pin, will be as great as the luminous ring produced by the inflecting power of the Moon at the same distance from both bodies. The ring of light, therefore, surrounding the Moon, will not exceed the luminous ring which Maraldi and Fouchy observed around their globes of wood and stone, and, therefore, could not possibly subtend a sensible angle at the distance of that luminary.

The appearance of the stars and planets, when eclipsed by the Moon, furnishes us with additional proofs of the existence of a lunar atmosphere. It was naturally expected by astronomers, that when the stars or planets came into contact with the Moon's limbs, they ought to suffer a change in their colour, arising from the transmission of their light through the densest part of the Moon's atmosphere. When we consider, however, that the lunar atmosphere, if its size were proportional to that of the earth, could not subtend a greater angle than one second, and that the emerging star moves through this space in two seconds, we are scarcely entitled to expect any considerable change in its brilliancy. Besides, the visible limb of the Moon may be formed by mountains, and the denser part of her atmosphere may be below their summits; so that the remaining part of the atmosphere, which is alone visible to us, may not have sufficient density to deaden the light of the emerging star. Cassini remarks, that he frequently observed the circular figure of Jupiter, Saturn, and the fixed stars, changed into an elliptical one, when they approached either the dark or the illuminated limb of the Moon. In the occultation of Saturn, observed by Mr. Dunn on the 17th June 1762, the ring and the body of Saturn appeared evidently to be affected by their proximity to the Moon, and had the appearance of a comet at the moment of emersion. M. le Monnier observed the star Aldebaran advanced as it were upon the illuminated disc of the Moon; but this must have been owing to some optical illusion.

Notwithstanding the force of the preceding arguments, the complete discovery of the Moon's atmosphere was reserved for the celebrated M. Schroeter of Lilienthal. This astronomer had frequently perceived, that the high ridges of the lunar mountains Leibnitz and Doerfel, when in the dark hemisphere,

were less illuminated in proportion to their distance from the boundary of light and darkness, and that the cusps were also more faintly illuminated than the other parts of the Moon's disc. He likewise observed "several obscurations and returning serenity, eruptions, and other changes in the lunar atmosphere;" from which he was led to expect, that a faint twilight might be perceived towards her cusps, as he had done in Venus.

By observing the Moon when her phases were extremely falcated, Schroeter at last discovered a faint glimmering light of a pyramidal form, extending from both cusps into the dark hemisphere, like *b c*, Figures 4 and 5. The greatest breadth of this crespuscular light was 2″ and its length 1′ 20″; from which Schroeter has computed, that the breadth of the lunar twilight, from the terminator or boundary of light and darkness, to where it loses itself in, and assumes the faint appearance of the light reflected from our Earth, measures, in a direction perpendicular to the terminator, 2° 34′ 25″; and, therefore, that the inferior or more dense part of the Moon's atmosphere is not more than 1500 English feet high, and that the height of the atmosphere, where it could affect the brightness of a fixed star, or inflect the solar rays, does not exceed 5742 English feet. This space subtends at our Earth only an angle of 0″.94, which will be passed over by the star in less than 2″ of time. The occultation of Jupiter on the 7th April 1792, was observed by Schroeter for the purpose of confirming the preceding discovery. Some of the satellites became indistinct at the limb of the Moon, while others did not suffer any change of colour. The belts and spots of Jupiter appeared perfectly distinct when close to the limb of the Moon, and a small luminous spot, though by no means very perceptible, could be plainly distinguished when close to the Moon's limb.

Plate II. *Sup.* Fig. 4, 5.

On the magnitude of the horizontal Moon.

When the Sun and Moon rise above the horizon, or set below it, they generally appear much larger than they do when seen on the meridian; though it is certain that they subtend a smaller angle in the former case than in the latter, when measured with a micrometer. When the place A, Fig. 1, has the Moon P in its meridian, the Moon is evidently nearer by more than 4000 miles, a semidiameter of the Earth, than when the place has come round to B, and has the Moon in its hori-

Plate XIV. Fig. 1.

zon. The extraordinary magnitude, therefore, of the Sun and Moon in the horizon, must be the result of some optical illusion. In explaining this singular phenomenon, astronomers have satisfied themselves with saying, that the sky does not appear like a circular hemisphere M N O P, but like an oval vault *m n o p*; the part of the zenith *o* seeming to be much nearer the eye of the spectator at E, than the horizon at *m*; and therefore that the horizontal Moon at *m* will be referred to a distance E *m*, and have the magnitude *m*, while the Moon in the zenith will be referred to a distance E *o*, and have the magnitude shewn at *o*. This explanation, however, only puts the difficulty a step farther off: for the question still recurs, Why does the zenith *o* appear nearer the Earth than the horizon O?

Plate IV. Sup. Fig. 8.

When we estimate the magnitude of remote objects, our judgment is formed by comparing them with adjacent objects whose magnitude is known. Thus, if we perceive a man standing upon a rock in the middle of the sea, we may form a tolerably correct estimate of the size of the rock by comparing it with the man, whose size may be reckoned about five feet eight inches; but if the rock is seen by itself, it is impossible to form any probable estimate of its magnitude. Hence a buoy seen at sea always appears much less than it really is. The same thing happens with regard to the estimation of distances. When many objects intervene, the mind is enabled to form an estimate approaching to accuracy; but at sea, where no objects intervene, the deception is enormous; and in like manner, in a mist, objects appear nearer and larger from the intervening objects being obscured and concealed. If an object is viewed in a horizontal line, or placed on the surface of the Earth, we are generally enabled to form a pretty accurate notion of its magnitude, by comparing it with adjacent or intervening objects. Thus the size of a ball placed before a house may be estimated by comparing it with the width of a window or a door, which is generally of a certain size; but if the ball is placed on the top of a spire, it is impossible to form a tolerable notion of its magnitude. To the writer of these remarks, the mosaic pavement in St. Paul's appeared about one-fifth of its real size when seen from the top of the cupola; but as soon as a man passed over it, the comparison corrected this erroneous estimate, and the pavement seemed to increase in magnitude. For the same

reason, the apparent size of the Moon when in the horizon is estimated by a comparison with intervening objects: but when she is at a considerable height above the horizon, she diminishes in size like the ball on the top of a spire. In order to obtain an experimental proof of this explanation, we smoked the surface of a mirror to imitate the horizontal vapours, and when the Moon had a considerable altitude, we reflected her image from the mirror, so that she appeared ruddy and near the horizon. In this case her size evidently increased, and when the horizontal Moon was reflected up to the zenith, her apparent magnitude was diminished. For the same reason, when the image of the Moon was reflected upon an object near the eye, it appeared extremely small, and when the image was thrown upon a distant object, it became very large.

Mr. Ezekiel Walker endeavours to account for the magnitude of the horizontal Moon by saying, that, on account of the diminution of the moonlight in the horizon, the pupil is more expanded than when the Moon is viewed at high altitudes, and that a larger image is on this account formed upon the retina. This opinion is demonstrably erroneous; for though the distance between two stars appears greater when they are in the horizon than in the zenith, it will not be maintained that the pupil is more expanded in the one case than in the other.

On the rotation of the Moon.

While the Moon is performing her monthly revolution, she always presents the same side to the Earth. This remarkable circumstance arises from her rotation about an axis in $29^d\ 12^h$, the same time that she revolves round the Earth; for if the Moon had no rotation upon an axis, she would exhibit every part of her surface to a spectator upon the Earth. If the Moon A, Fig. 1, were always to keep the same side A *v*, to the Earth at Æ, the line A *v* would not be carried parallel to itself; for when the Moon has reached G, the line A *v* will now have a position at right angles to *r s*, the Moon having performed a quarter of a revolution round her axis.

Plate VIII. Fig. 1.

From observations upon the lunar spots, Cassini found that the Moon revolves round an axis inclined 88° 17′ to the ecliptic, and that the nodes of the Moon's equator have the same position, and the same retrograde motion, as the nodes of the Moon's orbit.

The equality between the rotation and revolution of the

Moon was ascribed by Newton to her having an oval form, one side of which was denser than the other. La Grange, however, has shewn, that though the Moon ought to be elevated at the equator, by the diminution of the centrifugal force, yet the elevation is four times as great in the direction of the diameter of the equator that points to the Earth, in the same way as the waters of the Earth are always of a spheroidal form, the axis of the spheroid being directed to the Moon. In consequence of the attraction of the Earth upon this elevated portion, La Grange has shewn, that the velocity of the Moon's motion is sometimes accelerated and sometimes retarded; and that the tendency of this attraction is to produce an equality between the rotation and revolution of the Moon, even if they had been different, and to occasion a coincidence both in the position and motion of the nodes of the lunar equator and the lunar orbit. La Place supposes, that the high mountains of the Moon will have an influence upon these phenomena, and that this effect will be greater in proportion to the smallness of the compression at the lunar poles, and the smallness of her mass.

On the libration of the Moon.

If we examine with attention the disc of the Moon, we shall sometimes observe the spots on her eastern limb, which were formerly visible, concealed behind her disc, while others appear on her western limb which were not seen before. The spots which appear on her western limb withdraw themselves behind the limb, while the spots which were concealed behind the eastern limb again appear. The very same phenomena are observed in the north and south limb of the Moon, so that the spots sometimes change their position about three minutes on the Moon's disc. This phenomenon is called the *libration of the Moon*; which is of four different kinds, the *diurnal libration*, the *libration in longitude*, the *libration in latitude*, and the *libration arising from the action of the Earth on the lunar spheroid.* The two first of these were noticed by Galileo, the third by Hevelius, and the fourth by La Grange.

Diurnal libration. Plate V. Fig. 2.

If the disc of the Moon, supposed to be at S, in Fig. 2 of Plate V, is examined by persons situated at VI and XII, to the former of whom she appears in the horizon, and to the latter in the meridian, it is manifest that the person at VI will see a small portion of the Moon's north limb which the person at XII cannot perceive,

and that the person at XII will see a portion of the Moon's southern limb which is concealed from the spectator at VI. But when the spectator at VI is carried by the Earth's rotation into the position XII, or when the Moon comes to his meridian, he will lose sight of the part of the Moon's north limb which he formerly saw; and the part of the Moon's south limb, formerly concealed from him, will come into view. While he is carried from XII to VI, or when the Moon moves from his meridian to his horizon, he will perceive more and more of the Moon's south limb, and lose more and more of her north limb. These phenomena will be repeated every day; and the diurnal libration which is thus produced, will be proportional to the Moon's parallax in altitude.

Libration in longitude. The libration of the Moon in longitude arises from the inequalities of her motion round the Earth, combined with the uniformity of her motion round her axis. If the Moon moved uniformly in a circle round the Earth in its centre, she would always turn the same face to the Earth, and there would be no libration in longitude, the same spots appearing always at the borders of her eastern and western limb; or, what is the same thing, if the Moon moves unequally round her axis, and unequally in her orbit, the inequalities varying in the same manner, there would be no libration in longitude. But as the Moon moves unequally in an elliptic orbit round the Earth, placed in one of the foci, while she moves equally round her axis, she cannot present exactly the same face to the Earth. For since the two revolutions are performed exactly in the same time, the Moon will have performed more than one-twentieth, or any other part of her monthly revolution, when her motion is the quickest, in the time that she has performed one-twentieth of her revolution about her axis; so that the Earth has, as it were, got behind the Moon's eastern limb, and sees a part of it which was not visible before. In the same manner, when the Moon is near her perigee, where her motion is slowest, she will perform less than one-twentieth part of her monthly revolution in the same time that she performs one-twentieth part of her rotatory motion; so that the Earth will, as it were, be left behind, and get a view of the part of her western limb that was formerly concealed. The greatest libration in longitude happens when the Crisian sea is distant about three-fourths of its width from the western limb of the Moon.

The libration of the Moon in latitude arises from the inclination of her axis 88° 17′ to the ecliptic in which the Earth is placed. Had her axis been exactly perpendicular to the ecliptic, this libration would have vanished. During one half of her monthly revolution, the Moon's axis forms an acute angle with the radius vector, or line joining the Earth and Moon, varying between 88° 17′ and 90°, and, consequently, the north pole of the Moon, and the adjacent parts, comes into view, and the south pole is concealed; but, during the other half of her revolution, her axis forms an obtuse angle with the line joining the Earth and Moon, varying from 90° to 91° 43′; and therefore the north pole of the Moon, and the adjacent parts of her north limb, are withdrawn from the Earth, while the south pole comes into view.

Libration in latitude.

These three kinds of libration are merely optical, and do not affect the real rotation of the Moon. The fourth species, however, produces a little inequality in her rotation, as it arises from a small oscillation of the Moon about an axis perpendicular to the radius vector, produced by the action of the Earth on the elevated parts of the lunar spheroid.

Spheroidal libration.

CHAP VI.

ON ECLIPSES.

On eclipses.

The subject of eclipses has been already treated by Mr. Ferguson, in the 18th and 19th chapters of the first volume, at so great length, and with so much perspicuity, that we have no occasion to dwell any longer on that interesting part of astronomy. As the catalogues of eclipses, which are contained in the 18th chapter, extend no farther than the year 1800, we shall, in some measure, render them more complete, by presenting the reader with a catalogue of all the solar eclipses from the year 1769 till the year 1900. This catalogue, which we have abridged from the French of M. Du Vaucel in the *Memoires des Savans Etrangers*, was calculated from the tables of Mayer for the meridian of Paris, in order to gratify the French king, who was anxious to know if a total or annular eclipse would soon happen. It will appear, from the catalogue, that the only annular eclipse in the 19th century will take place on the 9th October 1847.

Table of Eclipses from 1769 to 1900.

	Time of Conjunction.	*Moon's Latitude then.*	*Beginning of the Eclipse.*	*Middle of the Eclipse.*	*End of the Eclipse.*	*Digits eclipsed.*
June 4, 1769,...............	8h 33′ 23″ M.	0° 55′ 45″ N.	6h 52′ 0″ M.	7h 46′ 30″ M.	8h 42′ 0′ M.	5° 22′ 0″
March 23, 1773,............	5 31 28 M.	0 42 17 N.	Sun rises ecl. 5h 52′		5 58 0 M.	1 0 0
January 9, 1777,...........	3 48 35 E.	0 40 25 N.	4 3 30 E.	Sun sets ecl. 4h 14′		1 37 0
June 24, 1778,..............	3 46 38 E.	0 18 56 N.	3 55 10 E.	4 47 20 E.	5 43 40 E.	6 28 0
June 14, 1779,..............	9 12 59 M.	1 4 41 N.	7 33 20 M.	8 18 40 M.	9 3 45 M.	2 50 0
April 23, 1781,.............	5 30 39 E.	0 3 40 S.	6 44 45 E.	Sun sets 7h 3′ 34″		1 25 0
October 17, 1781,..	9 20 49 M.	0 6 1 N.	7 3 0 M.	7 55 0 M.	8 34 0 M.	4 5 0
April 12, 1782.....	5 41 21 E.	0 37 17 N.	6 29 0 E.	Sun sets 6h 45′.		2 35 0
January 19, 1787,...... ...	10 56 0 M.	1 21 49 N.	9 50 0 M.	10h 44′ 0″ M.	11 13 0 M.	2 22 0
June 15, 1787,..............	4 2 48 E.	1 0 6 N.	4 31 0 E.	5 11 0 E.	6 7 0 E.	5 7 0
June 4, 1788,..	8 53 47 M.	0 15 11 N.	7 10 0	7 55 0	8 56 0	4 51 0
April 3, 1791,........		0 44 50 N.	12 45 0 Noon.	2 13 0 E.	3 31 0 E.	7 3 0
September 16, 1792,........	9 28 28 M.	0 1 12 S.	7 44 0 M.	7 57 0 M.	8 12 0 M.	0 7 0
September 5, 1793, ...	12 1 9 Noon.	0 41 19 N.	9 50 10 M.	11 25 50 M.	1 2 0 E.	8 56 0
January 31, 1794,..........	11 32 57 M.	1 20 53 N.	11 10 0 M.	12 3 0 Noon.	12 47 0 E.	2 43 0
June 24, 1797,..............	4 32 40 E.	1 0 18 N.	4 59 0 E.	5 40 0 E.	6 25 0 E.	4 0 0
August 28, 1802,...........	7 17 37 M.	0 41 10 N.	5 10 0 M.	6 2 0 M.	6 54 0 M.	4 5 0
August 17, 1803,...........	8 24 8 M.	0 0 51 S.	5 57 0 M.	6 46 0 M.	7 55 0 M.	3 7 0
February 11, 1804,.........	4 28 41 M.	0 42 1 N.	10 34 30 M.	11 50 0 M.	1 16 0 E.	9 21 0
June 16. 1806,..............	4 28 41 E.	0 54 0 N.	4 50 0 E.	5 32 0 E.	6 7 0 E.	3 7 0
November 29, 1807,........	12 3 36	0 31 33 N.	10 50 0	11 45 0	12 4[illegible] 0	3 7 0
February 1, 1813,..........	8 40 54 M.	0 41 13 N.	Sun rises 7h 10′ 34″	8 2 0 M.	9 15 0	8 3 0
July 17, 1814,..............	6 42 15 M.	0 10 1 N.	6 25 0 M.	6 31 0 M.	6 35 0 M.	0 8 0
November 19, 1816,........	10 28 16 M.	0 51 6 N.	8 24 0 M.	9 23 0 M.	10 41 0 M.	9 33 0
May 5, 1818,................	7 38 19 M.	0 30 32 N.	6 3 0 M.	6 55 0 M.	7 55 0 M.	3 1 0
September 7, 1820,.........	1 55 15 E.	0 44 43 N.	12 33 0	1 59 0	3 15 0	10 38 0
July 8, 1823,[1].............	6 50 36 M.	1 8 50				
November 29, 1826,........	11 42 14 M.	1 12 23 N.	10 5 0 M.	11 11 0 M.	12 21 0	6 34 0

[1] The Sun and Moon will be in contact 15h 40′ M. at Paris, but the Sun will be eclipsed to places at a greater distance from the equator.

	Time of Conjunction.	Moon's Latitude then.	Beginning of the Eclipse.	Middle of the Eclipse.	End of the Eclipse.	Digits eclipsed.
July 27, 1832,..............	2h 9′ 8″ E.	0° 5′ 46″ N.	2h 20′ 0″ E.	2h 43′ 0″ E.	3h 0′ 0″ E.	0° 45′ 0″
July 17, 1833,..............	7 22 10 M.	0 51 28 N.	5 7 0 M.	6 1 0 M.	6 53 0 [illegible]	7 47 0
May 15, 1836,..............	2 0 0 E.	0 26 24 N.	1 40 0 E.	3 12 0 E.	4 32 0 E.	9 40 0
July 18, 1841,..............	2 21 0 E.	1 13 14 N.	3 1 0 E.	3 14 0 E.	3 1 0 E.	0 30 0
July 8, 1842,..............	7 11 52	0 27 44 N.	5 0 30 M.	5 54 0 M.	6 52 0 M.	10 9 0
May 6, 1845,..............	10 6 21 M.	0 54 59 N.	8 24 0 M.	9 40 0 M.	10 43 0 M.	5 12 0
April 25, 1846,..............	5 0 0 E.	11 11 46 N.	5 42 0 E.	6 30 0 E.		3 42 0
October 9, 1847,[2]..........	9 22 26 M.	0 31 22 N.	6 27 0 M.	7 42 0 M.	9 3 0 M.	11 30 0
July 28, 1851,..............	3 48 5 E.	0 47 7 N.	2 14 0 E.	3 18 0 E.	4 17 0 E.	9 15 0
May 15, 1858,..............	12 15 6	0 38 13 N.	11 39 0 M.	1 6 0 E.	2 22 0 E.	10 45 0
July 28, 1860,..............	2 27 21 E.	0 31 45 N.	1 55 0 E.	3 5 0 E.	4 5 0 E.	9 32 0
December 31, 1861,........	1 51 28 E.	0 30 43 N.	2 5 0	3 4 0		6 13 0
May 17, 1863..............	5 4 13 E.	0 58 5 N.	6 0 0 E.	6 46 0 E.	7 30 0 E.	3 58 0
October 19, 1865,..........	4 47 12 E.	0 36 36 N.	4 23 0 E.			5 52 0
October 8, 1866,..........	5 24 46 E.	1 8 42 N.	5 2 0 E.	Sun sets 5h 32′		3 53 0
March 6, 1867,..............	9 19 21 M.	0 14 48 N.	7 51 0 M.	9 8 0 M.	10 29 0 M.	9 26 0
February 23, 1868,..........	2 15 27 E.	0 4 12 N.	3 42 0 E.	3 54 0 E.	4 6 0 E.	0 9 0
December 22, 1870.........	12 31 21	0 52 19 N.	11 21 0 M.	12 45 0 E.	2 5 0 E.	10 8 0
May 26, 1873,..............	9 38 30 M.	1 0 56 N.	7 56 0 M.	8 48 0 M.	9 34 0 M.	3 6 0
October 10, 1874...........	11 24 48 M.	0 53 15 N.	9 0 0 M.	10 29 0 M.	11 46 0 M.	3 36 0
September 29, 1875.........	1 13 53 E.	0 12 53 N.	11 56 0 M.	12 37 0 E.	1 7 0 E.	2 7 0
July 19, 1879,..............	9 40 2 M.	0 8 4 N.	7 45 0 M.	8 39 0 M.	9 41 0 M.	4 8 0
December 31, 1880,........	2 1 41 E.	1 11 32 N.	1 49 0 E.	2 47 0 E.	3 36 0 E.	4 28 0
May 17, 1882,..............	7 54 37 M.	0 19 16 N.	6 22 0 M.	7 0 0 M.	7 49 0 M.	3 19 0
August 19, 1887,..........	6 5 14 M.	0 39 4 N.	Sun rises ecl. 4h 41′		5 30 0 M.	8 13 0
June 17, 1890,..............	10 8 31 M.	0 13 58 N.	8 19 0 M.	9 22 0 M.	10 43 0 M.	5 46 0
June 6, 1891..............	4 39 57 E.	0 56 56 N.	5 14 0 E.	5 55 0 E.	6 40 0 E.	3 40 0
March 26, 1895,..............	10 10 51 M.	1 13 50 N.	9 25 0 M.	9 55 0 M.	10 57 0 M.	1 6 0
August 9, 1896,..............	5 12 20 M.	0 41 9 N.	Sun rises ecl. 4h 40′		4 42 0	0 15 0
June 8, 1899,..............	6 43 23 M.	1 5 50 N.	4 58 0 M.	5 35 0 M.	6 35 0 M.	2 25 0
May 28, 1900..............	3 16 41 E.	0 21 22 N.	3 21 0 E.	4 30 0 E.	5 23 0 E.	7 53 0

[2] *Distance of Centres.*—At the middle of the eclipse, 10″—Distance of the south limbs, 1′ 24″—Distance of the north limbs, 1′ 4″. This eclipse will be annular.

CHAP. VII.

ON OCCULTATIONS.

During the monthly motion of the Moon from west to east, in the heavens, she must appear to an inhabitant of the Earth to pass over such of the fixed stars as lie near her apparent path. The star which the Moon thus conceals from the Earth is said to suffer an *occultation*, or an eclipse. As the Moon's orbit is inclined to the ecliptic, and as the line of her nodes is constantly shifting, her apparent path in the heavens is subject to perpetual change; so that all those stars may suffer an occultation which are contained in a zone of the heavens, extending, on each side of the ecliptic, to the distance of the greatest latitude of the Moon's limb, as seen from the Earth. This zone is about 13° 12′ broad; and hence all those stars whose latitudes do not exceed 6° 36′ may suffer an occultation to the inhabitants of *some* parts of the Earth. All the stars situated within a zone 9° 4′ broad, or whose latitudes do not exceed 4° 32′, may suffer an occultation to the inhabitants of *any* part of the Earth. The most remarkable stars that lie within the broadest of these zones, with their longitudes and latitudes for 1820, according to the accurate observations of Bradley and Maskelyne, are contained in the following table.

	Longitude, 1820.				Latitude.				Magnitude
δ Aries,	1ˢ	18°	19′	55″	1°	48′	7″	N.	4
η Taurus, or *Alcione*,	1	27	28	55	4	1	36	N.	8
γ Taurus,	2	3	17	11	5	45	30	S.	3
ε Taurus,	2	5	56	48	2	35	37	S.	3.4
α Taurus, or *Aldebaran*,	2	7	16	23	5	28	46	S.	1
β Taurus,	2	20	3	48	5	21	59	N.	2
ζ Taurus,	2	22	16	27	2	13	29	S.	3
η Gemini,	3	0	55	48	0	55	4	S.	4.5
μ Gemini,	3	2	47	13	0	50	34	S.	3
γ Gemini,	3	6	35	31	6	46	12	S.	2.3
ε Gemini,	3	7	25	41	2	2	28	N.	3
δ Gemini,	3	16	0	40	0	12	19	S.	2
β Gemini, or *Pollux*,	3	20	43	45	6	40	19	N.	3
γ Cancer,	4	5	2	2	3	10	22	N.	4
δ Cancer	4	6	12	20	0	4	13	N.	4

	Longitude, 1820.				Latitude.				Magnitude.
ξ Leo,	4ˢ	19°	9′	30″	3°	9′	57″	S.	4
ο Leo,	4	21	44	49	3	46	1	S.	3.4
η Leo,	4	25	23	34	4	51	9	N.	3.4
α Leo, or *Regulus*,	4	27	19	38	0	27	38	N.	1
ρ Leo,	5	3	52	36	0	8	29	N.	4
τ Leo,	5	18	59	58	0	33	21	S.	4
υ Leo,	5	21	32	42	3	2	51	S.	4
β Virgo,	5	24	35	58	0	41	35	N.	3
c Virgo,	6	0	51	21	5	4	42	N.	4.3
η Virgo,	6	2	19	27	1	22	24	N.	3
γ Virgo,	6	7	39	52	2	48	57	N.	3
α Virgo, or *Spica*,	6	21	19	42	2	2	14	S.	1
α Libræ,	7	12	34	40	0	21	48	N.	2
1. ι Libræ,	7	18	29	18	1	49	14	S.	4.3
γ Libræ,	7	22	37	20	4	24	41	N.	3.4
η Libræ,	7	24	50	59	4	2	52	N.	4
κ Libræ,	7	25	14	58	0	1	1	N.	4
θ Libræ,	7	27	21	23	3	29	24	N.	4
λ Libræ,	7	27	57	57	0	6	53	N.	4
δ Scorpio,	8	0	3	39	1	57	17	S.	3
π Scorpio,	8	0	25	46	5	26	15	S.	3
β Scorpio,	8	0	40	44	1	4	58	N.	2
γ Scorpio,	8	2	8	1	1	39	52	N.	4
σ Scorpio,	8	5	17	24	4	0	23	S.	5
α Scorpio,	8	7	14	56	4	32	24	S.	1
τ Scorpio,	8	8	56	53	6	5	21	S.	4
γ Sagittarius,	8	28	45	14	6	56	48	S.	3
1. μ Sagittarius,	9	0	42	9	2	22	24	N.	4
λ Sagittarius,	9	3	58	42	2	5	31	S.	4
φ Sagittarius,	9	7	39	59	3	55	22	S.	5
σ Sagittarius,	9	9	52	28	3	24	55	S.	4.3
τ Sagittarius,	9	12	19	43	4	58	43	S.	4
ο Sagittarius,	8	12	28	47	0	53	36	N.	4
π Sagittarius,	9	13	44	32	1	28	7	N.	4
β Capricorn,	10	1	32	6	4	36	46	N.	3
ε Capricorn,	10	17	41	11	4	57	31	S.	4
γ Capricorn, or *Deneb Algedi*,	10	19	16	4	2	32	6	S.	4
δ Capricorn,	10	21	1	16	2	33	40	S.	3
ι Aquarius,	10	26	12	28	2	3	47	S.	4
θ Aquarius, or *Ancha*,	11	0	44	53	2	43	22	N.	4
λ Aquarius,	11	9	3	53	0	22	56	S.	4
φ Aquarius,	11	14	37	50	1	2	7	S.	5
δ Pisces,	0	11	38	21	2	9	44	N.	4
ε Pisces,	0	15	1	36	1	5	37	N.	4
ζ Pisces,	0	17	21	36	0	13	11	S.	4

The following more extensive table contains the right ascension and declination, with the annual variation of all stars not below the fourth magnitude, that are liable to be eclipsed by the Moon.[3] It includes, of course, the stars of the preceding Table.

1820. Jan. 1.				AR			Ann. Var.	N. P. D.			Ann. Var.	Angle of ☽'s Orbit with Meridian.	
				H.	M.	S.	S.	°	′	″	″	☽ asc.	☽ desc.
1	ε	71	♓	0	53	36,49	+3,11	83	4	49,0	—19,5	62°	72°
2	ζ	86	♓	1	4	19,90	3,11	83	22	41,1	19,3	62	72
3	η	99	♓	1	21	51,80	3,19	75	35	2,7	18,8	67	69
4	ν	106	♓	1	32	4,13	3,10	85	25	33,4	18,5	66	70
5	ο	110	♓	1	35	54,82	3,15	81	45	3,9	18,4	64	74
6	2ξ	73	Ceti	2	18	35,78	3,16	82	21	3,8	16,7		
7	μ	87	Ceti	2	35	13,10	3,20	80	39	3,7	15,6		
8	δ	57	♈	3	1	20,89	3,39	70	57	37,3	14,2	69	79
9	f	5	♉	3	20	56,73	3,28	77	41	11,3	12,9		
10	η	25	♉	3	36	47,43	3,53	66	27	32,7	11,8	73	79
11	A	37	♉	3	54	4,14	3,52	68	25	3,8	10,5	73	83
12	γ	54	♉	4	9	33,51	3,40	74	48	53,0	9,4		
13	1δ	61	♉	4	12	33,87	3,43	72	53	14,7	9,1	76	82
14	2δ	64	♉	4	13	43,73	3,43	72	58	51,0	9,1	77	83
15	2κ	67	♉	4	14	42,45	3,54	68	13	10,8	9,0	75	85
16	ε	74	♉	4	18	7,01	3,49	71	13	38,4	8,6	76	86
17	α	87	♉	4	25	36,02	3,43	73	51	39,2	8,0	80	81
18	ι	102	♉	4	52	20,54	3,57	68	40	33,9	5,9	78	88
19	β	112	♉	5	14	55,07	3,78	61	33	16,5	3,9	84	86
20	ζ	123	♉	5	26	53,36	3,57	68	58	35,9	3,0	81	91
21		132	♉	5	37	58,24	3,67	65	30	15,1	— 2,0	83	93
22	κ	44	Aur.	6	3	54,24	3,82	60	26	43,6	+ 0,2		
23	η	7	♊	6	4	0,64	3,63	67	27	2,2	0,2	85	95
24	μ	13	♊	6	12	3,09	3,63	67	24	13,8	1,2	86	96
25	ν	18	♊	6	18	16,35	3,55	69	40	59,7	1,5	87	95
26	ε	27	♊	6	32	51,07	3,69	64	42	1,3	2,8	88	98
27	ζ	43	♊	6	53	25,56	3,56	69	10	28,5	4,5	90	100
28	δ	55	♊	7	9	21,65	3,59	67	41	42,5	5,9	91	101
29	ι	60	♊	7	14	32,08	2,74	61	51	12,5	6,3		
30	υ	69	♊	7	24	49,05	+3,71	62	42	46,5	+ 7,1	96	98
31	κ	77	♊	7	33	34.03	3,63	65	10	44,1	7,9	95	103
32	γ	43	♋	8	32	51,08	3,49	67	53	27,3	12,4	100	108
33	δ	47	♋	8	34	26,42	3,43	71	11	26,2	12,7	100	110
34	1α	60	♋	8	46	4,97	3,29	77	41	30,7	13,2	104	106
35	2α	65	♋	8	48	37,81	3,29	77	27	4,3	13,5	104	106
36	ξ	5	♌	9	22	13,98	3,25	77	54	27,3	15,4	104	112
37	ο	14	♌	9	31	31,91	3,21	79	17	35,2	15,9	105	111

[3] This table is extracted from Mr. Pond's *Observations*, vol. ii.

1820. Jan. 1.				AR			Ann. Var.	N. P. D.			Ann. Var.	N.E. Angle of ☽'s Orbit with Meridian.	
				H.	M.	S.	S.	°	′	″	″	☽ asc.	☽ desc.
38	π	29	♌	9	50	41,36	3,18	81	5	44,6	16,9	106°	112°
39	η	30	♌	9	57	30,29	3,28	72	21	48,0	17,2	108	112
40	α	32	♌	9	58	46,43	3,21	77	9	23,0	17,3	105	115
41	ρ	47	♌	10	23	19,32	3,16	79	46	10,0	18,2	106	116
42	[illegible]	77	♌	11	11	51,08	3,10	82	59	5,6	19,6	108	118
43	(ι	78	♌)	11	14	31,00	3,11	78	28	42,0	19,6		
44	τ	84	♌	11	18	40,61	3,09	86	9	10,3	19,7	108	118
45	υ	91	♌	11	27	43,87	3,07	89	49	48,1	19,9	109	117
46	(β	5	♍)	11	41	18,84	3,12	87	13	14,7	20,0	108	118
47	η	15	♍	12	10	41,82	3,07	89	39	52,7	20,0	108	118
18	γ	29	♍	12	32	32,52	3,02	90	27	35,9	19,9	111	117
49	ϑ	51	♍	13	0	38,17	3,09	94	34	26,5	19,0	108	118
50	α	67	♍	13	15	43,25	3,15	100	13	2,4	19,0	107	117
51	i	68	♍	13	17	13,20	3,15	101	46	2,6	19,0	108	116
52	κ	98	♍	14	3	18,18	3,17	99	24	57,0	17,2	106	114
53	λ	100	♍	14	9	22,88	3,22	102	32	10,4	17,0	105	115
54	2α	9	♎	14	40	56,08	3,30	105	17	9,2	15,2	103	113
55	4ζ	35	♎	15	22	15,78	3,36	106	13	59,1	12,8	100	110
56	γ	38	♎	15	25	28,31	3,32	104	10	48,0	12,1	102	108
57	κ	43	♎	15	31	35,29	3,43	109	5	8,1	12,2	99	109
58	λ	45	♎	15	48	53,87	3,45	109	37	8,3	11,4	98	108
59	ϑ	46	♎	15	13	35,17	3,38	106	11	29,6	11,3	107	109
60	π	6	♏	15	47	58,66	3,59	115	35	8,0	11,0	94	104
61	ψ	48	♎	15	48	7,19	3,33	103	45	0,4	11,0		
62	δ	7	♏	15	49	42,26 +	3,51	112	5	55,6 +	10,9	97	107
63	1β	8	♏	15	51	56,11	3,47	109	18	8,7	10,5	97	107
64	2β	8	♏	15	54	59,58 +	3,47	109	17	55,5 +	10,5	97	107
65	ν	14	♏	16	1	32,69	3,46	108	58	57,3	10,0	96	106
66	σ	20	♏	16	10	15,74	3,61	115	8	58,0	9,3	98	104
67	α	21	♏	16	18	23,01	3,66	116	1	14,7	8,6	97	103
68	φ	8	Oph.	16	20	50,67	3,41	106	12	35,5	8,5	99	101
69	τ	23	♏	16	24	41,41	3,71	117	49	50,1	8,2		
70	A	36	Oph.	17	4	17,43	3,70	116	19	24,5	4,9		
71	ρ	40	Oph.	17	10	13.21	3,56	110	54	27,4	4,4	91	101
72	ϑ	42	Oph.	17	10	57,73	3,67	114	48	27,8	4,4	90	100
73	B	44	Oph.	17	15	22,77	3,64	113	59	50,0 +	4,0	90	100
74	1μ	13	♐	18	2	59,36	3,59	111	5	37,4 —	0,2	85	95
75	2μ	15	♐	18	4	28,73	3,59	110	46	11,0	0,3	85	95
76	δ	19	♐	18	9	28,02	3,84	119	53	30,0	0,7		
77	λ	22	♐	18	16	51,53	3,70	115	30	31,6	1,2	84	94
78	1ν	32	♐	18	48	17,80	3,62	112	57	15,7	3,6	81	91
79	σ	34	♐	18	44	5,88	3,73	116	30	21,5	3,6	82	90
80	ο	39	♐	18	53	53,29	3,59	111	59	35,7	4,6	81	91
81	τ	40	♐	18	55	41,89	3,75	117	55	15,8	4,7	84	86
82	π	41	♐	18	59	3,14	3,57	111	17	53,8	4,9	80	90
83	ψ	42	♐	19	4	29,57	3,68	115	33	17,7	5,5	80	88
84	d	43	♐	19	7	5,76	3,51	109	15	42,4	5,7		

1820. Jan. 1.			AR H.	M.	S.	Ann. Var. s.	N. P. D. °	′	″	Ann. Var. ″	N.E. Angle of ☽'s Orbit with Meridian. ☽ asc.	☽ desc.
85	b	59 ♐	19	45	53,11	3,69	117	38	10,0	8,8		
86	β	9 ♑	20	10	53,23	3,38	105	20	23,9	10,8	76°	80°
87	ϑ	23 ♑	20	55	48,76	3,37	107	56	23,0	13,8	6[illegible]	79
88	ι	39 ♑	21	26	59,04	3,37	110	15	54,8	15,7	70	74
89	γ	40 ♑	21	30	6,08	3,34	107	28	6,9	15,3	68	7[illegible]
90	δ	49 ♑	21	37	5,43	3,33	106	56	13,1	17,2	67	75
91	ϑ	43 ♒	22	7	19,36	3,17	98	40	27,8	17,5	66	74
92	2τ	71 ♒	22	40	3,13	3,19	104	32	48,3	18,8		
93	λ	73 ♒	22	43	13,09	3,13	98	32	0,5	18,9	63	73
94	φ	90 ♒	23	4	59,51	3,10	97	0	58,2	19,4	62	72
95	ω	28 ♓	23	50	4,03	3,05	84	7	55,1	20,0		

In order to find the time when the Moon will eclipse any of the stars in the preceding catalogue, or any others which lie within the zone already mentioned, we must find the time when the Moon is in conjunction with the star, or when the longitude of the Moon is the same as the longitude of the star. If the conjunction thus found happen at a time of the night when the star is visible, or within two hours of it, the occultation, if other circumstances render it one, will be visible. In order to find whether the Moon will pass above or below the star, or over it, so as to produce an occultation, we must compute her parallax in latitude, which, subtracted from the Moon's *true* latitude, if it is north, and added to it, if it is south, will give her *apparent* latitude, as seen from the surface of the Earth at the given place. If the difference between the Moon's apparent latitude thus found, and the latitude of the star, does not exceed the Moon's semi-diameter, she will pass over the star, and produce an occultation. When this difference exceeds the Moon's semi-diameter, and when the latitude of the star is less than that of the Moon, then the Moon will pass above the star if her latitude is north, and below it if her latitude is south; but when the star's latitude is greater than that of the Moon, she will pass below it when her latitude is north, and above it when her latitude is south. As the calculation of the parallax of latitude is a tedious operation, we shall subjoin the following table, suited to the latitude of 51° 32′, and computed with great labour, for every second degree of the right ascension of the mid-heaven, which is one of the arguments for taking out the Moon's

parallax in latitude, her horizontal parallax being the other argument.

The right ascension of the mid-heaven is equal to the Sun's right ascension in degrees, added to the distance of the given time from the preceding noon, converted into degrees, &c. by the Table in vol. i, p. 108. The method of finding the parallax of latitude from the following tables will be understood by an example.

Let it be required to find the Moon's parallax of latitude at London on the 16th December 1812, at 10^h 15′ apparent time, the Moon's horizontal parallax being 60′ 32″.

Distance from the preceding noon, 10^h 15′, converted into time by the Table in vol. i, p. 108,	153°	45′	0″
Sun's right ascension then,	264	55	30
	418	40	30
Subtract 12 signs,	360	0	0
Right ascension of the mid-heaven north,	58	40	30

When the sum is above 360°, as in the preceding example, subtract 360 from it, and the result will be the right ascension of the mid-heaven, for entering the Table, and taking out the parallax in latitude. If the sum is between 90 and 180, subtract it from 180°; if it is between 180 and 270, subtract 180° from it: and if it is between 270 and 360, subtract it from 360°.

The right ascension of the mid-heaven being 58° 40′ north, enter Table I, and with 58° 40′ at the side, and the Moon's horizontal parallax, 60′ 32″, at the top, the parallax in latitude will be found to be 30′ 28″.

Table I. Containing the Moon's Parallax in Latitude, to every Second Degree of the Right Ascension of the Mid-heaven, for lat. 51° 32′.

Right Ascension of the Mid-heaven.	Moon's Horizontal Parallax.															
NORTH, or less than 180 degrees.	54′ 59″		56′		57′		58′		59′		60′		61′		61′ 24″	
°		″	′	″	′	″	′	″	′	″	′	″	′	″	′	″
0	39	29	40	12	40	56	41	39	42	22	43	5	43	48	44	6
1	39	15	39	58	40	41	41	24	42	7	42	49	43	32	43	48
2	39	1	39	44	40	26	41	9	41	52	42	34	43	15	43	32
4	38	34	39	17	40	1	40	41	41	23	42	5	42	47	43	4
6	38	4	38	46	39	27	40	9	40	50	41	32	42	13	42	32
8	37	36	38	17	38	58	39	39	40	20	41	1	41	42	42	0
10	37	7	37	48	38	29	39	9	39	50	40	30	41	10	41	28
12	36	39	37	19	38	0	38	40	39	20	40	0	40	39	40	56
14	36	11	36	51	37	31	38	11	38	50	39	29	40	8	40	24
16	35	44	36	23	37	2	37	41	38	20	38	59	39	37	39	52
18	35	16	35	55	36	34	37	12	37	51	38	29	39	7	39	24
20	34	49	35	28	36	6	36	44	37	22	38	0	38	37	38	52
22	34	23	35	1	35	38	36	16	36	53	37	31	38	8	38	23
24	33	55	34	33	35	10	35	47	36	24	37	1	37	38	37	53
26	33	30	34	8	34	44	35	21	35	57	36	34	37	10	37	25
28	33	5	33	41	34	18	34	54	35	30	36	6	36	41	36	56
30	32	39	33	15	33	51	34	27	35	3	35	38	36	14	36	28
32	32	16	32	51	33	27	34	2	34	37	35	12	35	47	36	1
34	31	52	32	27	33	2	33	37	34	11	34	46	35	20	35	35
36	31	29	32	3	32	38	33	12	33	46	34	21	34	55	35	9
38	31	4	31	39	32	13	32	47	33	21	33	54	34	28	34	42
40	30	43	31	17	31	51	32	25	32	58	33	32	34	3	34	18
42	30	22	30	55	31	29	32	2	32	34	33	8	33	41	33	54
44	30	1	30	55	31	7	31	40	32	13	32	46	33	18	33	31
46	29	41	30	14	30	46	31	19	31	51	32	23	32	55	33	8
48	29	22	29	54	30	26	30	58	31	30	32	2	32	34	32	48
50	29	3	29	35	30	6	30	38	31	10	31	32	32	13	32	26
52	28	45	29	16	29	48	30	19	30	51	31	22	31	53	32	6
54	28	28	28	59	29	30	30	1	30	32	31	4	31	34	31	47
56	28	16	28	39	29	10	29	41	30	11	30	42	31	13	31	25
58	27	56	28	26	28	57	29	28	29	53	30	28	30	59	31	11
60	27	41	28	11	28	41	29	12	29	42	30	8	30	42	30	55
62	27	27	27	57	28	27	28	57	29	37	29	57	30	27	30	39
64	27	15	27	44	28	14	28	45	29	13	29	43	30	13	30	25
66	27	3	27	32	28	1	28	31	29	1	29	30	30	2	30	12
68	26	51	27	21	27	50	28	19	28	49	29	18	29	47	29	59

TABLE I,—concluded.

Right Ascension of the Mid-heaven. NORTH, or less than 180 degrees.	Moon's Horizontal Parallax.							
	54' 59"	56'	57'	58'	59'	60'	61'	61' 24"
°	' "	' "	' '	' "	' "	' "	' "	' "
70	26 41	27 10	27 39	28 8	28 37	29 6	29 35	29 47
72	26 32	27 1	27 30	27 59	28 28	28 57	29 25	29 37
74	26 23	26 52	27 21	27 50	28 19	28 47	29 16	29 28
76	26 16	26 45	27 13	27 42	28 11	28 39	29 8	29 20
78	26 9	26 38	27 7	27 35	28 4	28 32	29 1	29 12
80	26 4	26 53	27 1	27 30	27 58	28 26	28 55	29 7
84	25 56	26 21	26 53	27 21	27 49	28 18	28 46	28 58
87	25 53	26 21	26 49	27 18	27 46	28 14	28 42	28 24
89	25 51	26 20	26 48	27 16	27 44	28 13	28 40	28 52
90	25 51	26 20	26 58	27 16	27 44	28 13	28 40	28 52

TABLE II. Containing the Moon's Parallax in Latitude, to every Second Degree of the Right Ascension of the Mid-heaven.

Right Ascension of the Mid-heaven. SOUTH, or more than 180 degrees.	Moon's Horizontal Parallax.							
	54' 59"	56'	57	58'	59'	60'	61'	61" 24"
°	' "	' "	' "	' "	' "	' "	' "	' "
0	39 29	10 12	10 56	11 39	42 22	43 5	43 48	44 6
1	39 43	10 27	41 10	41 54	42 37	43 20	44 3	44 20
2	39 57	40 11	41 25	42 9	42 52	43 36	44 19	44 36
4	40 26	11 11	41 55	42 39	13 23	44 7	44 51	45 8
6	40 54	41 39	42 24	13 9	13 54	44 38	45 22	45 40
8	41 23	42 8	42 54	43 39	44 24	45 9	45 54	46 12
10	41 51	42 37	43 23	44 9	44 54	45 40	46 25	46 44
12	42 19	43 5	43 52	44 38	45 24	46 10	46 56	47 16
14	42 47	43 34	44 21	45 8	45 54	46 41	47 27	47 44
16	43 14	44 2	44 50	45 37	46 24	47 11	47 57	48 16
18	43 41	44 30	45 17	46 5	46 53	17 40	48 27	48 48
20	44 9	44 57	15 46	46 34	47 22	48 10	48 58	49 8
22	44 36	45 25	46 14	47 2	17 51	48 40	49 28	49 48
24	45 0	45 50	16 39	47 29	48 18	49 7	49 55	50 15

Table II,—concluded.

Right Ascension of the Mid-heaven.	Moon's Horizontal Parallax.															
SOUTH, or more than 180 degrees.	54′ 59″		56′		57′		58′		59′		60′		61′		61′ 24″	
°	′	″	′	″	′	″	′	″	′	″	′	″	′	″	′	″
26	45	27	46	17	47	7	47	57	48	46	49	36	50	24	50	47
28	45	53	46	43	47	33	48	24	49	13	50	3	50	53	51	14
30	46	17	47	8	47	59	48	50	49	40	50	31	51	20	51	41
32	46	42	47	34	48	25	49	16	50	7	58	58	51	42	52	9
34	47	6	47	58	48	50	49	41	50	33	51	25	52	15	52	36
36	47	30	48	22	49	14	50	6	50	58	51	50	52	41	53	2
38	47	53	48	46	49	38	50	31	51	23	52	15	53	7	53	28
40	48	15	49	8	50	1	50	54	51	46	53	39	53	31	53	53
42	47	36	49	30	50	23	51	16	52	9	53	2	53	55	54	16
44	48	57	49	51	50	45	51	38	52	32	53	25	54	18	54	40
46	49	18	50	12	51	6	52	0	52	53	53	47	54	40	55	2
48	49	37	50	32	51	26	52	21	53	15	54	9	55	3	55	24
50	49	56	50	51	51	45	52	40	53	35	54	29	55	23	55	46
52	50	17	51	12	52	7	53	2	53	57	54	52	55	46	56	8
54	50	31	51	27	52	19	53	18	54	13	55	8	56	2	56	24
56	50	47	51	43	52	39	53	35	54	30	55	25	56	19	56	43
58	51	3	51	59	52	55	53	51	54	46	55	42	56	37	57	0
60	51	17	52	13	53	9	54	6	55	2	55	58	56	53	57	16
62	51	32	52	28	53	24	54	21	55	17	56	13	57	9	57	32
64	51	45	52	41	53	37	54	34	55	30	56	27	57	23	57	46
66	51	57	52	53	53	50	54	47	55	43	56	40	57	37	58	0
68	52	8	53	5	54	2	54	59	55	56	56	53	57	49	58	13
70	52	18	53	15	54	12	55	10	56	7	57	4	58	1	58	24
72	52	28	53	25	54	22	55	20	56	17	57	14	58	11	58	34
74	52	35	53	33	54	30	55	28	56	25	57	23	58	20	58	43
76	52	43	53	41	54	39	55	36	56	34	57	31	58	28	58	52
78	52	49	53	47	54	45	55	43	56	40	57	38	58	35	58	59
80	52	55	53	53	54	51	55	49	56	46	57	44	58	42	59	5
84	53	3	54	1	54	59	55	57	56	55	57	53	58	51	59	14
87	53	6	54	4	55	2	56	0	56	58	57	56	58	54	59	18
89	53	7	54	6	55	4	56	2	57	0	57	58	58	56	59	20
90	53	7	55	6	55	4	56	2	57	0	57	58	58	56	59	20

Without the aid of the Moon's parallax in latitude, we may find, in some cases, by the following rule, whether or not any conjunction is attended with an occultation. If the difference between the latitude of the Moon and that of the star exceeds 1° 37′, no occultation can take place; and if the difference be

less than 51′, there must be an occultation to some part of the Earth. When the difference lies between these limits, we must have recourse to the Moon's parallax in latitude, to ascertain whether or not an occultation will take place.

If it appears that an occultation will happen, we must then find, from astronomical tables, or from the nautical almanack, the longitude and latitude of the Moon at the time of conjunction, the longitude and latitude of the star, the horary motion of the Moon in longitude at the time of conjunction; the horary motion of the Moon in latitude, the horizontal parallax of the Moon, the semi-diameter of the Moon; and the time when the star passes the meridian of the place. With these elements we may project the occultation, as in the following example.

Example.—Let it be required to find whether or not the conjunction of the Moon with Aldebaran, in the month of December 1812, will be attended with an occultation; and, if it is, to find the time of the immersion and emersion of the star, by projection.

By comparing the longitude of the Moon with that of the star, it will at once appear that the conjunction will take place on the 16th of December, when the longitude of Aldebaran, according to Dr. Maskelyne, is $2^s\ 7^\circ\ 10'\ 29''$, and its latitude $5^\circ\ 28'\ 47''$ south. It will appear, also, from the calculation of the Moon's place, either by Mason's Tables, or from the Nautical Almanack, that the conjunction takes place at $10^h\ 20'\ 37''$ apparent time, at Greenwich, when the Moon's longitude is $2^s\ 7^\circ\ 10'\ 20''$, her latitude $4^\circ\ 53'\ 13''$ south, her hourly motion in longitude $37'\ 3''$, her hourly motion in latitude $50''$, her horizontal parallax $60'\ 32''$, and her horizontal semi-diameter $16'\ 30''$. In order to determine whether or not an occultation will accompany this conjunction, we must find, from the preceding tables, the Moon's parallax in latitude; thus,

Time past noon, viz. $10^h\ 20'\ 37''$, converted into degrees of the equator,	155°	9′	15″
Right ascension of the Sun then,	264	27	15
Sum,	419	36	30
Subtract 12 signs,	360	0	0
Right ascension of the mid-heaven north,	59	36	30

With this argument we obtain from the Table, p. 206, 30′ 30″, for the Moon's parallax of latitude, which, added to the Moon's latitude, 4° 53′ 13″, because it is south, gives 5° 23′ 43″ for the Moon's apparent latitude. The difference between the latitude of the star and the Moon's apparent latitude being 5′ 4″, which is less than the Moon's apparent semi-diameter, the star must suffer an occultation.

Before we proceed to point out the method of projecting this and other occultations, we must first find the inclination of the axis of the ecliptic to the circle of latitude corresponding to the point of the ecliptic in which the star is placed, or what is enough at present, the distance of the star from the nearest solstitial point; and likewise the angle of the Moon's visible path with the ecliptic. For this purpose, subtract the longitude of the star from 3ˢ, if its longitude is between 0ˢ and 3ˢ, or from 9ˢ, if its longitude is between 6ˢ and 9ˢ; but if the longitude of the star is between 3ˢ and 6ˢ, subtract 3ˢ from it, and if it is between 9ˢ and 12ˢ, subtract 9ˢ from it, and the remainder will be the distance of the star from the nearest solstitial point. Thus,

In the present case, the longitude of the star is 2ˢ 7° 10′ 29″, between 0ˢ and 3ˢ, so that we have	3ˢ	0°	0′	0″
	2	7	10	29
Distance of Aldebaran from the nearest solstitial point, reckoned on the ecliptic, ...	0	22	49	31

In order to find the angle of the Moon's visible path with the ecliptic, say, as the Moon's hourly motion in longitude is to her hourly motion in latitude, so is radius to the tangent of the angle of the Moon's visible path with the ecliptic. Thus,

As 37′ 3″ or 2223″	3.3469395
Is to 0 50	1.6989700
So is R. 90 0	10.0000000
To the tangent of the angle of the Moon's path, 1° 17′ 19″	8.3520305

Let us now collect all the elements which are necessary for projecting the occultation.

1. Apparent time of conjunction in December 1812, ...	16^d	10^h	20′	37″
2. Longitude of the Moon and of Aldebaran then, ...	2^s	7°	10	29
3. Latitude of the Moon south, decreasing or ascending to the north, ...	0	4	53	13
4. Latitude of Aldebaran south, ...	0	5	28	47
5. Difference of latitude, ...	0	0	35	34
6. Distance of Aldebaran from the nearest solstitial point, ...	0	22	49	31
7. Hourly motion of the Moon in longitude, ...	0	0	37	3
8. Hourly motion of the Moon in latitude, ...	0	0	0	50
9. Moon's horizontal parallax, ...	0	1	0	32
10. Moon's horizontal semi-diameter, ...	0	0	16	30
11. Right ascension of the Sun in time, ...	0	17^h	37	49
12. Right ascension of Aldebaran in time, ...	0	4	25	12
13. Time of Aldebaran's southing, or the difference between the Sun's right ascension and that of the star, ...	0	10	47	23
14. Declination of Aldebaran north, ...	0	16°	7	23
15. Angle of the Moon's visible path with the ecliptic, ...	0	1	17	19

Method of projecting Occultations of the Fixed Stars and Planets by the Moon.

From a scale of equal parts C B of any conve- Plate IV.
nient length, take, with the compasses, 60′ 32″, the *Sup.* Fig. 9.
Moon's horizontal parallax, or the semi-diameter of the Earth's disc, and having described the semicircle A H B, which will represent the northern half of the Earth's disc, draw C H at right angles to A B, for the axis of the ecliptic. Make C A the radius of the line of chords on the sector, and having taken from it the chord of 23° 30′ set it from H to *m* and *n*, and draw the line *m n*, cutting C H in T. With T *m* or T *n* as the radius of the line of sines in the sector, take the sine of 20° 49′ 31″, the distance of Aldebaran from the nearest solstitial point, and set it from T to P on the right hand of C H, the axis of the ecliptic, when the longitude of the star is 9^s, 10^s, 11^s, or 1^s, 2^s; but on the left hand of C H when the longitude of the star is 3^s, 4^s, 5^s, 6^s, 7^s, or 8^s.

From the line of chords on the sector, with the radius C A, take 38° 31′ the co-latitude of Greenwich, and set it from *o*, where C P meets the circle, to Z and Y, and draw the dotted line Z L Y. With C A as radius, take the declination of Aldebaran, 16° 7′ 23″, from the line of chords, and set it both ways from Z and Y to D and F, and to E and G, and draw the dotted lines D E and F G. Bisect the line X X in K, and draw the dark line IV, K, IV perpendicular to C K. Take

the distance o Z, or o Y, which is the chord of 38° 31′ the co-latitude of Greenwich, and set it from K to IV and IV.

With K IV as the radius of the line of sines, set off K *a*, K *a′*, equal to the sine of 15°; K *b*, K *b′*, equal to the sine of 30°; K *c*, K *c′*, equal to the sine of 45°; K *d*, K *d′*, equal to the sine of 60°; and K *e*, K *e′*, equal to the sine of 75°; and through these points draw occult dotted lines parallel to X K X. Then, with K X as the radius of the line of sines, take the sine of 75°, and set it from *a* to IX, and from *a′* to XI, on both sides; set the sine of 60° from *b* to VIII, and from *b′* to XII, on both sides; set the sine of 45° from *c* to VII, and from *c′* to I, on both sides; set the sine of 30° from *d* to VI, and from *d′* to II, on both sides; and, finally, set the sine of 15 degrees from *e* to V, and from *e′* to III. Then, through the points IV, V, VI, VII, VIII, IX, X, XI, XII, I, II, III, IV, V, &c. draw the ellipsis IV, X, IV, X, which will represent the path of Greenwich on the Earth's disc. The half-hours might have been drawn upon the elliptical path, by taking the sines for every 7½°, and the quarters, by taking the sines for every 3¾°. At the points where the elliptical path cuts the line C *o*, put 10ʰ 47′, the time of the star's southing, and continue the hours all the way round the circumference of the ellipse, as in the figure, the time of the star's southing being always placed at the extremity of the conjugate axis of the ellipse. The lower side of the ellipse represents the path of Greenwich when the star is above the horizon, if its declination is north; but the upper part of the ellipse will represent the path of Greenwich when the star is above the horizon, if its declination is south.

With C B as the radius of the line of chords, take 1° 17′ 19″, the angle of the Moon's visible path with the ecliptic, and set it from H to M, on the right hand of H, since the Moon's latitude is decreasing, or since she is ascending north towards the ecliptic. When her latitude is descending, the point M will lie on the left hand of H.

Take the difference between the latitude of the Moon and Aldebaran, viz. 0° 35′ 34″, and set from C to *x* upon the line C M, and through the point *x* draw the line R S perpendicular to C M for the path of the Moon.

Take the Moon's hourly motion in longitude, 37′ 3″, from the scale C B, and making it the length of a separate scale, divide it into 60 equal parts for minutes. Take 47′ 23″, the time

of the conjunction after 10 o'clock, and from this scale, set it from *x* towards the left hand on the line of the Moon's path, the other point will mark out the hour of X. Take the whole length of the separate scale in the compasses, and set it from X to XI, from XI to XII, and from X to IX, and divide each of these spaces into single minutes, or into every five and ten minutes.

Apply one side of a square to the Moon's path R S, and move it backwards and forwards till the other side cuts the same hour and minute in the path of the Moon, and in the path of Greenwich, as at *r* and *s*. The instant thus found, which, in the present case, is 10^h 32′, will be the moment of visible conjunction, or the middle of the occultation.

Take the Moon's semi-diameter, 16′ 30″, from the scale C B in your compasses, and setting one foot on the Moon's path, on the right hand of C M, and the other on the path of Greenwich, move them backwards and forwards, keeping each foot upon its proper path, till both the feet fall upon the same hour and minute in each path as at *w*. This particular time, which, in the present case, is 9^h 53′, will be the beginning of the occultation, or the instant when the star immerges behind the eastern limb of the Moon. Do the very same on the other side of C M, and you will obtain the end of the occultation, or the time when the star emerges from behind the western limb of the Moon, which, in the present case, is 11^h 11′. With the Moon's semi-diameter as radius, and upon the points *t*, *r*, *w*, as centres, viz. the beginning, middle, and end of the occultation, describe three circles, which will represent the position of the Moon at the beginning, middle, and end of the occultation, while the points *w*, *s*, and *v*, will represent the position of the star at these instants respectively, *r s* being the nearest approach of the centres of the Moon and star, or 1′ 30″. From the projection we therefore obtain the following results:—

Beginning of the occultation,	9^h	53′	0″
Middle of the occultation,	10	32	0
End of the occultation,	11	11	0
Duration of the occultation,	1	18	0
Nearest approach of centres,	0°	1	30

The method of projection which we have now explained will answer for occultations of the planets, as well as the fixed stars, with this difference only, that in the former case, instead of the hourly motion of the Moon in longitude and latitude, we must take the hourly motion of the Moon and planet, if they are moving in the same direction, or their difference, if they are moving in opposite directions, for the relative hourly motion in longitude and latitude. With this relative hourly motion we must find the inclination of the relative orbit, in the same manner as we found the angle of the Moon's visible path with the ecliptic.

The method of computing the various phenomena of occultations, without the aid of projection, will be seen in La Lande's Astronomy, tom. ii, and in Hutton's *Miscellanea Mathematica*. See also Vince's *Astronomy*, vol. i, and Dr. O. Gregory's *Astronomy*, p. 368.

A very neat method of computing visible occultations will be found in the *Journal of Science*, vol. x, p. 161; and in the same work, p. 152, will be found a table containing the names of the stars that will suffer an occultation when the Moon's node has different positions.

CHAP. VIII.

ON TRANSITS.

As Mr. Ferguson has already given a full account of the doctrine of transits, and of the method of projecting them, in Chapter XXIII of this volume, we have nothing of importance to add upon that subject. It may not be uninteresting, however, to many of our readers, to be put in possession of the elements of all the transits of Mercury which have happened during the last century, and which are still to happen during the present; and likewise the elements of all the transits of Venus, from 1631 to 2984.

TABLE I. Containing the Transits of Mercury over the Sun's Disc for three Centuries, calculated from LA LANDE's Tables.

Years.	Conjunction. Mean Time at Greenwich.	Geocentric Longitude of the Sun and Mercury.	Middle Apparent Time.	Semiduration of the Transit.	Nearest Ap. of Centres of the Planets.
	h ′ ″	s ° ′ ″	h ′ ″	h ′ ″	′ ″
1605	Nov. 1, 7 36 52	7 9 28 34	8 14 48	1 20 14	14 5 S.
1615	May 2, 21 39 39	1 12 25 35	22 3 48	3 27 54	7 37 N.
1618	Nov. 4, 1 29 54	7 12 5 6	1 54 49	2 33 25	5 42 S.
1628	May 5, 5 47 21	1 15 30 47	5 23 45	3 9 34	9 41 S.
1631	Nov. 6, 19 26 59	7 14 41 35	19 34 40	2 41 20	2 40 N.
1644	Nov. 8, 13 3 49	7 17 17 36	13 4 31	1 58 27	10 48 N.
1651	Nov. 2, 14 22 9	7 10 36 30	13 1 57	1 45 25	12 20 S.
1661	May 3, 4 39 17	1 13 33 27	4 53 24	3 48 0	4 26 N.
1664	Nov. 4, 6 17 27	7 13 7 51	6 39 38	2 38 44	4 2 N.
1671	May 6, 12 41 4	1 16 38 5	12 8 25	2 15 12	13 4 S.
1677	Nov. 7, 0 8 46	7 15 15 57	0 27 27	2 36 20	4 15 N.
1690	Nov. 9, 17 56 39	7 18 20 46	17 56 50	1 48 5	12 12 N.
1697	Nov. 2, 17 32 39	7 11 33 50	18 1 58	1 58 13	10 37 S.
1707	May 5, 11 18 58	1 14 40 0	11 25 16	3 57 8	0 58 N.
1710	Nov. 6, 11 10 3	7 14 10 50	11 29 39	2 42 18	2 20 S.
1723	Nov. 9, 5 6 39	7 16 47 20	5 11 10	2 29 20	6 0 N.
1736	Nov. 10, 22 50 2	7 19 23 38	22 45 50	1 21 14	13 58 N.
1740	May 2, 10 27 16	1 12 43 49	12 4 40	1 30 0	14 44 N.
1743	Nov. 4, 22 16 47	7 12 37 32	22 46 10	2 15 55	9 5 S.
1753	May 5, 18 20 29	1 15 48 0	18 17 40	3 53 22	2 23 S.
1756	Nov. 6, 16 8 7	7 15 13 41	16 26 59	2 42 37	1 2 N.
1769	Nov. 9, 9 57 46	7 17 50 49	10 1 44	2 23 46	7 29 N.
1776	Nov. 2, 9 0 46	7 11 3 36	9 40 33	0 36 42	15 43 S.
1782	Nov. 12, 3 39 22	7 20 26 41	3 31 50	0 37 22	15 43 N.
1786	May 3, 17 2 28	1 13 49 45	16 35 0	2 44 10	11 21 N.
1789	Nov. 5, 3 0 29	7 13 40 48	3 27 40	2 26 9	7 22 S.
1799	May 7, 1 4 29	1 16 51 11	1 53 1	3 42 22	5 31 S.
1802	Nov. 8, 20 47 41	7 16 16 27	21 2 10	2 43 19	1 0 N.
1815	Nov. 11, 14 34 58	7 18 52 42	14 36 58	2 13 52	9 14 N.
1822	Nov. 4, 13 53 13	7 12 6 53	14 30 14	1 21 37	14 0 S.
1832	May 4, 23 51 22	1 14 56 45	0 18 1	3 28 2	8 16 N.
1835	Nov. 7, 7 47 54	7 14 43 8	8 12 22	2 33 53	5 37 S.
1845	May 8, 7 51 18	1 18 1 49	7 32 58	3 22 33	8 58 S.
1848	Nov. 9, 1 37 43	7 17 19 19	1 49 43	2 41 33	2 36 N.
1861	Nov. 11, 19 20 13	7 19 54 44	19 20 14	2 0 23	10 52 N.
1868	Nov. 4, 18 43 45	7 13 9 42	19 18 21	1 45 21	12 20 S.
1878	May 6, 6 38 30	1 16 3 50	6 55 14	3 53 31	4 39 N.
1881	Nov. 7, 12 39 38	7 15 46 57	12 59 33	2 39 6	3 57 S.
1891	May 9, 14 44 57	1 19 9 1	14 13 46	2 34 20	12 21 S.
1894	Nov. 10, 6 17 5	7 18 22 9	6 36 29	2 37 36	4 20 N.

*** The aberration of the Sun and Mercury, and the small equations of the Sun's place, neglected in the preceding Table, give 6′ 30″ to be added to the calculated time of the conjunction.

TABLE II. Containing the Transits of Venus over the Sun's Disc for two thousand Years, calculated from LA LANDE's *Tables.*

Years.	Conjunction. Mean Time at Greenwich.				Geocentric Longitude of the Sun and Venus.				Middle Apparent Time.			Semiduration of the Transit.			Nearest Ap. of Centres of the Planets.		
	OLD STYLE.	h	′	″	s	°	′	″	h	′	″	h	′	″	′	″	
902	Nov. 25,	21	7	36	8	9	2	55	20	33	44				18	14	N.
910	Nov. 22,	9	9	18	8	6	33	47	9	33	39	3	39	26	6	15	S.
1032	May 24,	6	35	29	2	8	37	45	6	33	0	3	51	29	3	16	S.
1040	May 21,	23	6	31	2	6	29	9	23	47	48				6	16	N.
1145	Nov. 25,	19	50	46	8	11	1	30	19	17	30				17	7	N.
1153	Nov. 23,	7	52	13	8	8	32	21	8	19	2	3	31	56	7	22	S.
1275	May 25,	10	12	3	2	10	57	7	10	4	8	3	42	52	5	18	S.
1283	May 23,	2	44	3	2	8	48	30	3	19	56	1	41	58	14	14	N.
1388	Nov. 25,	18	33	28	8	13	0	3	18	4	9	0	41	52	16	2	N.
1396	Nov. 23,	6	39	2	8	10	31	12	7	8	2	3	23	40	8	24	S.
1518	May 25,	13	46	50	2	13	16	22	13	33	19	3	29	28	7	21	S.
1526	May 23,	6	16	41	2	11	7	35	6	47	45	2	28	57	12	16	N.
	NEW STYLE.																
1631	Dec. 6,	17	18	29	8	14	58	50	16	52	23	1	35	5	11	56	N.
1639	Dec. 4,	6	0	20	8	12	32	15	6	30	20	3	17	0	9	0	S.
1761	June 5,	17	35	14	2	15	36	31	17	20	50	3	8	0	9	30	S.
1769	June 3,	9	58	34	2	13	27	8	10	27	3	2	59	53	10	10	N.
1874	Dec. 8,	16	8	24	8	16	57	49	15	13	28	2	4	41	13	51	N.
1882	Dec. 6,	4	16	24	8	14	29	14	4	49	42	3	1	43	10	29	S.
2004	June 7,	20	51	24	2	17	54	23	20	26	59	2	44	50	11	19	S.
2012	June 5,	13	17	40	2	15	45	22	13	37	26	3	20	45	8	20	N.
2117	Dec. 10,	14	57	17	8	18	56	52	14	34	1	2	22	50	13	0	N.
2125	Dec. 8,	3	9	20	8	16	28	33	3	44	31	2	48	20	11	28	S.
2247	June 11,	0	21	3	2	20	13	16	23	51	14	2	7	52	13	17	S.
2255	June 8,	16	44	36	2	18	4	1	16	59	10	3	36	2	6	23	N.
2360	Dec. 12,	13	49	49	8	20	56	9	13	29	32	2	42	47	11	49	N.
2368	Dec. 10,	2	0	42	8	18	27	18	2	38	6	2	29	22	12	37	S.
2490	June 12,	3	49	15	2	22	31	58	3	13	59	1	2	14	15	14	S.
2498	June 9,	20	12	42	2	20	22	37	20	20	59	3	46	21	4	29	N.
2603	Dec. 15,	12	44	56	8	22	55	36	12	25	55	2	56	47	10	50	N.
2611	Dec. 13,	1	1	52	8	20	27	38	1	40	31	2	15	20	13	20	S.
2733	June 15,	7	14	36	2	24	50	30	5	33	53				17	9	N.
2741	June 12,	23	34	39	2	22	40	56	23	47	39	3	53	23	2	35	N.
2846	Dec. 16,	11	43	55	8	24	55	22	11	26	26	3	7	21	9	55	N.
2854	Dec. 14,	0	4	9	8	22	27	45	0	44	21	1	54	10	14	12	S.
2984	June 14,	2	53	2	2	24	59	1	2	51	53	3	56	9	0	45	N.

*** The transits of 902, 1040, 1045, 2490, 2733, are doubtful. The aberration of Venus, and the small equations of the Sun's place, neglected in the preceding Table, give 2′ 20″ to be added to the calculated time of the conjunction.

CHAP. IX.

ON THE ABERRATION OF THE HEAVENLY BODIES, THE PRECESSION OF THE EQUINOXES, THE NUTATION OF THE EARTH'S AXIS, AND THE VARIATION IN THE OBLIQUITY OF THE ECLIPTIC.

It can scarcely be expected, in a work like this, that we should enter at any length into the subjects of this chapter. The greater part of them are among the most difficult branches of physical astronomy; and we have been induced to notice them at present, chiefly in order to supply a defect in the original work. We shall endeavour to explain to our readers the physical cause of these interesting phenomena; though, without the aid of mathematical reasoning, any explanation, however simple, must be imperfect and unsatisfactory.

On the Aberration of the Stars.

While Dr. Bradley was engaged in a series of observations to determine the parallax of the Earth's annual orbit, or the angle which the Earth's orbit subtends at any fixed star, he discovered a change in the places of some of the stars, which he called their *Aberration*, and which he afterwards found to arise from the motion of light, combined with the annual motion of the Earth in its orbit.

Aberration of the stars.

In order to understand how these motions combined should produce a change in the places of the stars, let *a*, *b*, *c*, *d*, *e*, represent the path of a particle of light emitted by the star S, and perpendicular to the plane of the Earth's orbit A B C D, and let us suppose the telescope I *m* to be carried along with the Earth, in its annual orbit A B C D. That an observer, looking through the telescope, may see the star S, he must not direct the telescope to the place S, where the star really is, but he must incline it to the direction of the light which comes from the star, and must point it towards *s*, so that the star will appear at *s*, instead of at S, having S *s* for its aberration, or the

Plate V. Sup. Fig. 1.

difference between its true and apparent place. In order to prove this, let us suppose that the velocity of the Earth in its orbit A B C D, is the same as the velocity of light; that the telescope is in the position 1 *m* when the particle of light is at *a*, and that, while the particle moves from *a* to *b*, from *b* to *c*, from *c* to *d*, and from *d* to *e*, the telescope moves through the equal spaces, 1, 2; 2, 3; 3, 4; 4, 5, respectively. The moment the telescope has reached the position 2 *m*, the particle will have arrived at *b*, and, by means of it, the star will be visible through the telescope. When the telescope has advanced to the position 3 *o*, the particle of light will have arrived at *c*, and, by means of it, the star will still be visible through the telescope. In the same manner, when the telescope has successively reached the positions 4 *p*, 5 *q*, the particle will have arrived at *d* and *e*, successively, so that the particle of light has really moved along the axis of the telescope, without touching its sides; and, consequently, the star S, from which the particle of light was emitted, must have been visible in the direction of the tube's axis, and must have appeared in the heavens somewhere about *s*. As the velocity of light is supposed to be equal to the Earth's annual motion, the inclination of the telescope to the path of the particle *a*, *b*, *c*, *d*, *e* must be 45°, and the aberration of the star 45°; but since the real velocity of light is nearly 10,313 times greater than that of the Earth in its orbit, the inclination of the telescope will require to be only 20″, to allow the particle of light to pass freely along its axis, and consequently S *s*, the aberration of the star, will be only 20″.

It is manifest, from the explanation now given, that the aberration is always in the direction in which the telescope or the Earth is moving. Thus, in the progress of the Earth along the side of its orbit A B, the aberration will be in the direction S *s*; when the Earth is moving from B to C, at right angles, to its former direction, the aberration will be S *t*; when the Earth is moving from C to D, the aberration will be S *v*, and when it is moving along D A, the aberration will be S *w*. Now S *s*, S *t*, S *v*, S *w*, are each 20″, and consequently the star will describe a small circle in the heavens, *s t v w*, 40″ in diameter. Since *s* is the apparent place of the star, when the Earth is between A and B; *t* its apparent place, when the Earth is between E and A; *v* its apparent place, when the Earth is at N; and *w* its

apparent place, when the Earth is at F: it follows that the star S will always appear 90° farther advanced in its small circle *s t v w*, than the Earth will be in its own orbit.

Hitherto we have supposed that the star S is in the pole of the ecliptic A B C D, and consequently that the path *a b c d e* of the particles of light emitted by the star is at right angles to the motion of the Earth in its orbit; in which case the aberration will be greatest, and will always be 20″. If the star is situated at P in the plane of the Earth's orbit, or in the plane of the ecliptic, and if the Earth is at E, moving in the direction E G, at right angles, nearly to E P, the aberration will be 20″, as formerly, and the star will appear in the heavens at *u*. During the progress of the Earth from G to N, the direction of its motion is gradually becoming more oblique to the [illegible] of light emitted by the star, and consequently the aberration will gradually diminish, and the star will appear nearer and nearer its true place, till the Earth arrives near N, when the aberration will vanish, as the Earth and the light of the star are both moving in the same direction. While the Earth is moving from N to F, the aberration will gradually increase in the opposite direction P *r*; and when the Earth arrives at F, it will again be 20″, and the star will appear at *r*, the direction of the light of the star being now at right angles to the path of the Earth. During the progress of the Earth from F to M, the aberration will again diminish, and vanish at M; and during its motion from M to C, it will again increase, and reach its maximum at E. From this we may conclude, that the aberration of a star situated in the plane of the ecliptic is the greatest possible when it is in opposition and conjunction with the Sun, and that it vanishes when the star is in the quadratures. Between the quadratures and the conjunctions and oppositions, the aberration varies as the sine of the star's distance from the quadratures. When the star is placed in the pole of the ecliptic, or in the plane of the ecliptic, the aberration, being always in the direction of the Earth's motion, will consequently be in the direction of the ecliptic, and will therefore affect only the longitude of the star, and its right ascension and declination. If the star, however, is above or below the ecliptic, and not in its pole, its latitude will also be affected; but, in all cases, the aberration will be greatest when the star is in opposition and conjunction, and least when it is in

Plate V. Sup. Fig. 1.

quadrature, with the Sun. The aberration, however, will not vanish in the quadratures, as the Earth and the light of the star can never move in exactly the same, or in exactly the opposite, direction, unless when it is situated in the ecliptic.

Aberration of the planets. Plate V. *Sup.* Fig. 2.

The true places of the planets are likewise changed by the combined motion of the Earth and the light which they emit. Let Jupiter be supposed immoveable at O, and let B A be the space described by the Earth in the time that the light of Jupiter moves from O to A, or rather the relative motion of the Earth and Jupiter in that time; then it is obvious that when the Earth has reached *b*, the light of Jupiter will have arrived at *d*; and when the Earth has arrived at A, the light will be at A, so that B O or *b d* will be the direction in which the planet is seen, or the direction in which a telescope carried along with the Earth must be placed, in order that the light of Jupiter may always move along its axis. When the Earth is at *b*, Jupiter will consequently appear at *o*, instead of O, so that its aberration O *o* is equal to the space B *b*, described by the Earth in the time that the light moves from O to *d*. When the Earth arrives at A, Jupiter will appear at *o*′, and his aberration O *o*′ will be equal to the space B A, described by the Earth in the time that his light moves from O to A. Since light employs 8′ 7″ to come from the Sun to the Earth, and since the Earth moves through 20′ in that time, the aberration of the Sun will be 20″. In the same way, we shall have, for the greatest aberration of the other planets,

Sun,...........................	20″	Ceres,..........................	32″
Mercury,......................	59½	Jupiter,........................	29
Venus,.........................	43½	Saturn,........................	26
Mars,...........................	36	Georgium Sidus,..	25

These numbers will vary with the elongation of the planets from the Sun, and with a variation of their position in their own orbits[1].

[1] A full account of the history of this discovery will be found in the Edinburgh Encyclopædia, *Art. Aberration.*

On the Precession of the Equinoxes.

We have already seen (vol. I, § 247), that the two opposite points, where the ecliptic and equator intersect each other, are called the *Equinoctial Points*, and the line which joins them the *Line of the Equinoxes*. These points are not stationary in the heavens, but retreat along the ecliptic, contrary to the order of the signs, at the rate of 50″.3 in a year, so that they perform a whole revolution in the heavens in about 26,000 years. Since the longitudes of the stars, therefore, are reckoned from the vernal equinoctial point, and since this point recedes on the ecliptic, the longitudes of the stars must increase 50″.3 every year. The cause of this singular phenomenon we shall now endeavour to explain. Precession of the Equinoxes.

Let N S be the Earth, N its north, and S its south pole, Æ Æ the equator, inclined to the plane of the Moon's orbit A B, and *a b d*, $\alpha \beta \delta$ the meniscus of redundant matter at the equator, by which the globe of the Earth exceeds an accurate sphere. Let the Moon now move round the Earth supposed at rest, and it will act upon the redundant matter *a b d*, $\alpha \beta \delta$, in the direction of lines drawn to the Moon, from each particle of the redundant matter. Thus, if the Moon is at M, its action on the particle at Æ will be in the direction of Æ M; and this force may be resolved into two, one in the direction Æ N, parallel to the Moon's orbit, and the other in the direction Æ P, perpendicular to the plane of the Moon's orbit. In the same way, it may be shewn, that in whatever part of her orbit the Moon is, the force with which she attracts each particle of redundant matter, whether in the inferior meniscus $\alpha \beta \delta$ or in the superior meniscus *a b d*, may be decomposed into two forces, one of which draws the particle in a direction parallel to the plane of the Moon's orbit, while the other draws the particle down to the plane of the Moon's orbit. The forces which act parallel to the plane have obviously no tendency to alter the distance of the particles from the plane; but those which act perpendicularly have a direct tendency to draw the particles down to the plane, and thus to diminish the angle Æ C M, or the inclination of the Earth's equator to the plane of the Moon's orbit, the intersection C suffering no change of position. Plate V. Sup. Fig. 3.

Plate V. Sup. Fig. 4. Let us now suppose the Earth to be put in motion round its axis, then all the particles of the redundant matter will receive a motion parallel to the equator Æ Æ. Let the particle Æ, moving in the direction Æ .C, be drawn towards the plane of the Moon's orbit, by a force which would make it describe the space Æ P in the same time that the particle itself, by the diurnal motion of the Earth, would describe the space Æ T. Draw T *e* parallel to Æ P and P *e* parallel to Æ T, then Æ *e* will be the direction in which the particle will move, when acted upon by the two separate forces Æ P, Æ T. Hence it will cut the ecliptic in the point *c* at a greater angle than it did before, and proceed in the direction Æ *c* T′. The equinoctial point, therefore, which was formerly at C, will have moved backwards to *c*, and the inclination of the equator will be increased, while the particle is moving towards the equinoctial point *c*. When the particle has passed the point *c*, it is still drawn to the plane of the Moon's orbit. Let us suppose it at Æ′, and that the force drawing it to the plane of the Moon's orbit would make it describe the space Æ′ P′, in the same time that it is carried from Æ′ to T′ by the Earth's motion; then, in virtue of these two forces, it will move in the direction Æ′ *e*′, as if it had come from c′. The equinoctial point *c*, therefore, has moved still farther along the ecliptic, in the same retrograde direction, the recession having been C *c* while the particle was moving from Æ to *c*, and *c* *c*′ while it was moving from *c* to *c*′. We have already seen, that the inclination of the path of the particle, in its passage from Æ to *c*, was increased from the angle Æ C B to the angle Æ *c* B; but, in its passage from *c* to *e*′, its inclination has diminished from the angle Æ′ *c* A to the angle *e*′ *c*′ A; so that, upon the whole, the Moon's inclination has not suffered any change, having been increased in the one case, and diminished in the other. The action of the Moon upon every other particle of redundant matter will produce similar changes; and hence it follows, that the action of the Moon upon the equatorial parts of the Earth produces a recession or precession in the equinoctial points. The space C *c*′ is the precession during one revolution of the Moon, which does not exceed 3″. The whole effect produced by the Moon during a year is 35″.2. The Sun will evidently act upon the equatorial parts of the Earth in a similar manner, and will produce a similar effect; but, on account of the great distance of

this luminary, the precession occasioned by its action is only 15″.1, the whole precession arising from the combined action of the Sun and Moon being 50″.2 every year.

On the Nutation of the Earth's Axis.

On the nutation of the Earth's axis.

In observing the declination of γ Draconis, and other stars, Dr. Bradley perceived a change in their declination, for which he long attempted to discover a cause. He found, however, that such changes were different in different years, and that they seemed to depend on the position of the Moon's nodes.

Plate V. Sup. Fig. 3.

If the angle Æ C M, which the Earth's axis makes with the plane of the Moon's orbit, had been always the same, as it would have been if the Moon's nodes had been stationary, then the precession of the equinoxes would have been uniform, and the Earth's axis would always have pointed to the same part of the heavens. But since the Earth's equator is inclined 23° 30′ to the ecliptic, and since the Moon's orbit is also inclined about 5° 30′ to the ecliptic, the Moon's orbit must, in certain positions of her nodes, be inclined about 29° to the Earth's equator, and in other positions 18°; and during 18 years, the time in which her nodes perform a complete revolution, the plane of her orbit will have every possible inclination to the Earth's equator between the limits of 18° and 29°. Now, it is manifest, from Fig. 3, that the force Æ P, by which the particles of redundant matter are attracted to the plane of the Moon's orbit, must increase or diminish with the angle Æ C M, the angle which the equator forms with the Moon's orbit. If this angle remained constant, the precession would remain constant, and the obliquity of the ecliptic would also be invariable; but since the angle Æ C M varies, in the course of 18 years, from 18° to 29°, and from 29° to 18°, the perpendicular force Æ P is always increasing and diminishing; and hence there is not only an irregularity in the precession of the equinoxes, but also a nutation of the Earth's axis, or a change in the obliquity of the ecliptic. The force Æ P, therefore, increasing for nine years, will produce a change of inclination, or a change in the angle Æ C M, which is not counteracted by another change of an equal and opposite kind; and as it will diminish during the next nine years, the inclination will

also increase till it reaches its former magnitude. This variation will amount to 18″ at the end of 18 years, the Earth's axis having described a small circle in the heavens, about 9″ in diameter. By this nutation of the Earth's axis, the equator will change its place in the heavens; and, consequently, the declination of the fixed stars will increase and diminish during every revolution of the Moon's nodes.

On the Diminution of the Obliquity of the Ecliptic.

Diminution of the Obliquity of the Ecliptic.

The obliquity of the ecliptic to the equator was long considered as a constant quantity; and even so late as the end of the 17th century, the difference between the obliquity, as determined by ancient and modern astronomers, was generally attributed to inaccuracy of observation, and to a want of knowledge of the parallaxes and refraction of the heavenly bodies. It appears, however, from the most accurate modern observations, made at great intervals, that the obliquity of the ecliptic is diminishing; and the theory of universal gravitation fortunately supplies us with a satisfactory explanation of the phenomenon.

While the Earth is revolving in the plane of the ecliptic, it is acted upon by all the planets of the solar system. The action of any of the planets, when they are situated in the plane of the ecliptic, has a tendency only to alter the Earth's gravity to the Sun, or to accelerate and retard its motion; but as all the planets move in orbits inclined to the ecliptic, their action upon the Earth tends to bring the Earth towards the plane of their orbits, in the manner which we have already explained, when treating of the precession of the equinoxes. The effect of this action, therefore, is to displace the ecliptic, or diminish the inclination of the Earth's orbit to the plane of the orbit of the planet; but while the Earth's orbit is thus changing its position, the equator of the Earth is sustaining no change, and consequently there will be a variation in the obliquity of the ecliptic to the equator. Along with this variation, there will also be a small precession in the equinoctial points. These changes, however, are very small, and scarcely become apparent till after the lapse of ages. According to La Grange, the diminution in the obliquity of the ecliptic and the precession of the equinoxes produced by the different planets in a century are,

	Var. in Obliquity.		Precession.
Mercury	0″.84	+	0″.85
Venus,	30 .88	+	8 .87
Mars,	1 .03	+	0 .95
Jupiter,	15 .86	—	2 .11
Saturn,	2 .39	—	0 .53
Total effect,	50″.00	+	8″.03

By comparing about 160 observations of the obliquity of the ecliptic, made by ancient and modern observers, with the obliquity of 23° 28′ 16″, as observed by Tobias Mayer, in 1756, we have found, from a view of all the results, that the diminution of the obliquity of the ecliptic, during a century, is 51″; a result which accords wonderfully with the best observations.

Description of a Machine for exhibiting the Precession of the Equinoxes.

A very ingenious machine, which is represented in Plate VIII, *Sup.* Fig. 1, was contrived several years ago by M. Bohnenberger of Tubingen, for exhibiting experimentally the phenomenon of the precession of the equinoxes. Upon the pedestal H there is firmly fixed, by means of screws, a vertical ring of brass A B A second ring C D is connected with A B, by means of the pivots *a b*, so that it may move with as little friction as possible round the vertical axis *a b*. To the ring C D a third ring E F is joined by means of two pivots *c d* (*d* being invisible to the eye), in order that the ring E F may revolve with facility round a horizontal axis, passing through *c d*, and at right angles to that which passes through *a b*. A spheroid K representing the Earth, and having *m n* for its equator, and *e f* for its axis, is made to revolve upon an axis *e f* at right angles to *c d*. The spheroid K must be constructed with great care, in such a manner that its matter is uniformly distributed, both in relation to its axis and to the equator, and with this view there is a ring of lead of uniform density and shape placed within it, and coincident with the equator *m n*. This uniformity in its density is a point of great importance, as the existence of a hollow space in the lead produces an irregularity in the motion of the spheroid. When the machine is thus constructed, it is ob-

vious that the axis *ef* of the globe K may be made to take every possible position with regard to a horizontal plane.

Upon the axis *ef* there is placed a cylinder, part of which is seen to the left hand of *f*, and by coiling a silk thread round this cylinder, and holding the rings C D, E F, steadily with the left hand, the globe K may be thrown into a state of quick rotation, by pulling the thread smartly with the right hand. When this is done, the axis *ef* will maintain an invariable position, even if we lift the machine off the table, and carry it about the room; and if we apply any gentle force to the ring E F, with the view of changing its inclination, we shall find that it has a strong tendency to resist any change of position.

The machine in this condition may represent the Earth revolving round its axis, and uninfluenced by any external action. But if we now attach to the ring E F a weight G, by fixing it at the points *g*, *h*, and then put the globe K into a state of rapid motion, we imitate the action of the Sun and Moon upon the equatorial parts of the Earth, which have a constant tendency to disturb its regular rotation. The consequence of the application of this weight will be to produce a slow conical motion of the axis *ef* round the vertical axis *a b;* and the node or the point of intersection of the equator *m n*, and a horizontal plane, representing the ecliptic, will move uniformly in a direction contrary to that in which the globe K revolves. A full account of this machine, by Bohnenberger himself, will be found in *Tubingen Blatter*, 1817, iii Bandes, p. 72, and in a mathematical investigation of its theory, by Poisson in the *Journal de l'Ecole Polytechnique*, tom. ix, cap. 16, p. 247

CHAP. X.

ON COMETS.

Comets are a class of celestial bodies, which appear occasionally in the heavens. They exhibit no visible or defined disc, but shine with a pale and cloudy light, accompanied with a tail or train turned from the Sun. They are found in every part of the heavens, and move in all possible directions.

When examined through a good telescope, a comet resembles a mass of aqueous vapours encircling an opaque nucleus of dif-

ferent degrees of darkness in different comets, though sometimes, as in the case of several discovered by Dr. Herschel, no nucleus can be seen. As the comet advances towards the Sun, its faint and nebulous light becomes more brilliant, and its luminous train gradually increases in length. When it reaches its perihelion, the intensity of its light, and the length of its tail, reach their maximum, and sometimes it shines with all the lustre of Venus. During its retreat from the perihelion, it is shorn of its splendour, it gradually resumes its nebulous appearance, and its tail decreases in magnitude till it reaches such a distance from the Earth, that the attenuated light of the Sun, which it reflects, ceases to make an impression on the organ of sight. Traversing unseen the remote portion of its orbit, the comet wheels its ethereal course far beyond the limits of our system. What region it there visits, or upon what destination it is sent, the limited powers of man are unable to discover. After the lapse of years, we perceive it again returning to our system, and tracing a portion of the same orbit round the Sun, which it had formerly described.

It would be a waste of time to detail the various wild and extravagant opinions which have been entertained respecting these interesting stars. During the ages of barbarism and superstition, they were regarded as the harbingers of awful convulsions, both in the political and in the physical world. Wars, pestilence, and famine, the dethronement of kings, the fall of nations, and the more alarming convulsions of the globe, were the dreadful evils which they presented to the diseased and terrified imaginations of men. As the light of knowledge dissipated these gloomy apprehensions, the absurdities of licentious speculation supplied their place, and all the ingenuity of conjecture was exhausted in assigning some rational office to these wandering planets. Even at the beginning of the 18th century, the friend and companion of Newton regarded them as the abode of the damned. Anxious to know more than what is revealed, the fancy of speculative theologians strove to discover the frightful regions in which vice was to suffer its merited punishment; and the interior caverns of the Earth had, in general, been regarded as the awful prison-house in which the Almighty was to dispense the severities of justice. Mr. Whiston, however, outstripped all his predecessors in fertility of invention. He pretended not only to fix the residence of

the damned, but also the nature of their punishment. Wheeled from the remotest limits of the system, the chilling regions of darkness and cold, the comet wafted them into the very vicinity of the Sun; and thus alternately hurried its wretched tenants to the terrifying extremes of intolerable cold and devouring fire.

By other astronomers, comets were destined for more scientific purposes. They were supposed to convey back to the planets the electric fluid which is constantly dissipating, or to supply the Sun with the fuel which it perpetually consumes. They have been regarded, also, as the cause of the deluge; and we must confess, that if a natural cause is to be sought for that great event, we can explain it only by the shock of some celestial body. The transient effect of a comet passing near the Earth could scarcely amount to any great convulsion; but if the Earth were actually to receive a shock from one of these bodies, the consequences, as La Place has shewn, would be awful. A new direction would be given to its rotatory motion, and the globe would revolve round a new axis. The seas, forsaking their ancient beds, would be hurried by their centrifugal force, to the new equatorial regions; islands and continents, the abodes of men and animals, would be covered by the universal rush of the waters to the new equator, and every vestige of human industry and genius at once destroyed. The chances against such an event, however, are so very numerous, that there is no dread of its occurrence.

Various opinions have been entertained by astronomers respecting the tails of comets. These tails sometimes occupy an immense space in the heavens. The comet of 1681 stretched its tail across an arch of 104 degrees; and the tail of the comet of 1769 subtended an angle of 60° at Paris, 70° at Boulogne, 97° at the isle of Bourbon, and 90° at sea, between Teneriffe and Cadiz. These long trains of light were supposed by Appian, Cardan, and Tycho Brahe, to be the light of the Sun transmitted through the nucleus of the comet, which they believed to be transparent like a lens. Kepler thought that the impulsion of the solar rays drove away the denser parts of the comet's atmosphere, and thus formed the tail. Descartes ascribes the tail to the refraction of light by the nucleus. Newton maintained that it is a thin vapour raised by the heat of the Sun from the comet. Euler asserts that the tail is occasioned

by the impulsion of the solar rays driving off the atmosphere of the comet; and that the curvature observed in the tail is the joint effect of this impulsive force, and the gravitation of the atmospherical particles to the solid nucleus. Mairan imagines that comets' tails are portions of the Sun's atmosphere. Dr. Hamilton of Dublin supposes them to be streams of electric matter; and Biot supposes with Newton that the tails are vapours produced by the excessive heat of the Sun; and also that the comets are solid bodies before they reach their perihelion, but that they are afterwards either partly or totally converted into vapour by the intensity of the solar heat.

In the early ages of science, the comets were regarded as an assemblage of small stars that had accidentally coalesced into one body; and afterwards they were believed to be simple meteors or exhalations generated by inflammable vapours in the Earth's atmosphere. A few of the ancient philosophers entertained more correct notions of the nature of comets. Some of them considered these bodies as a species of planets that moved in regular orbits beyond the region of the Moon; but this was only a sagacious conjecture which they had founded neither on observation nor analogy. It was not till the time of Tycho that actual observation was called to the aid of theory, and that any well-founded opinion was maintained. By observing the comet of 1577, he found that it had no diurnal parallax; and that it was therefore situated at a much greater distance than the Moon. Kepler, who at first thought that they described rectilineal paths, afterwards endeavoured to shew that their orbits were parabolic and concave towards the Sun. Hevelius entertained the same opinion; but it was left for Sir Isaac Newton to show, that comets revolved like planets round the Sun, in eccentric ellipses, stretching far beyond the limits of the solar system, as is represented in Plate I, *Sup.* where the aphelion part of the orbit is not drawn on account of its great distance from the Sun.

On the return of comets.

Pursuing the opinion of Sir Isaac Newton, the celebrated Dr. Halley collected all the observations upon comets, and calculated the elements of 24 of them. He was so much struck with the similarity between the elements of the comets of 1456, 1531, 1607, and 1682, that he believed them to be the same comet that had performed three complete revolutions, between 1456 and 1682, with periods of

From 1531 to 1607 .... 76 years 62 days.
From 1607 to 1682 .... 74 years 323 days.

Hence he predicted that the same comet would return in 1757 or 1758; and that its period would be lengthened by the action of Jupiter and Saturn.

This curious subject was taken up by Clairaut, who computed the separate effects produced by Jupiter and Saturn on the motion of the comet of 1682. He concluded that the attraction of Jupiter ought to lengthen its period 510 days, while that of Saturn should only lengthen it 100; and that instead of 74 years and 323 days, its period should be 76 years and 211 days. As the comet, therefore, passed its perihelion on the 14th September 1682, it ought, by this calculation, to reach the same point of its path on the 13th of April 1759. The appearance of this comet was therefore eagerly anticipated as a phenomenon which would establish on an immoveable basis the theory of universal gravitation. It accordingly appeared about the end of December 1758, and arrived at its perihelion on the 13th of March, only 30 days before the time fixed by Clairaut By repeating his calculations, he afterwards reduced this error to 19 days.

The comet of 1815, which reached its perihelion on the 26th April, appears also to revolve in an elliptical orbit, whose greater axis is less than that of the Georgium Sidus, and less even than that of the comet of 1759. The period of its sidereal revolution is about 73 years, so that it may be expected to reappear in the year 1888.

Comet of 1770. The comet of 1770 appears to have experienced very remarkable changes from the action of the planets. According to Pingre, it moved in an orbit whose major semiaxis was 3.14786, and had a period of 5.43 years. The calculations of Lexell make its major semiaxis 3.14786, and its period 5.585 years. As this comet has never been seen since 1770, the National Institute very lately requested Mr. Burckhardt to repeat all the calculations with the utmost care; and the result of his labour has been a complete confirmation of the elements obtained by Lexell. He found its major semiaxis to 3.14359, and its period 5.575 years. What has become of this comet it is difficult to say. The aphelion part of its orbit is not far beyond the orbit of Jupiter. It approaches as near to the

Earth as the Moon, and ought to have appeared about eight times since the year 1770.

Theory of the loss of the Comet of 1770.

We are unwilling to hazard a conjecture upon a subject like this; but the circumstances are so remarkably curious, that we hope to be pardoned for indulging in speculation. In Chapter II, we have shewn that the four new planets are the fragments of a large celestial body which once existed between Mars and Jupiter; and we have adduced several arguments to prove that this body may have burst by some internal convulsion. If this body had an atmosphere, each of the four fragments would obviously carry off a portion of it, according to their respective magnitudes; but it is a very singular circumstance, that while two of the fragments, Juno and Vesta, are entirely free from any nebulous appearance, the other two fragments, Ceres and Pallas, are surrounded with a nebulosity of a most remarkable size. In the case of Ceres, this nebulosity is 675 English miles high: while the nebulosity of Pallas extends 468 miles from the body of the planet. It is obvious that such immense atmospheres could not have been derived from the original planet, otherwise Juno and Vesta would also have been encircled with them; so that they must have been communicated to Ceres and Pallas since the planet was burst. Now, the comet of 1770, if it is lost, must have been attracted by one of the planets whose orbit it crossed, and must have imparted to it its nebulous mass; but none of the old planets have received any addition to their atmosphere; consequently, it is highly probable that the comet has passed near Ceres and Pallas, and imparted to them those immense atmospheres which distinguish them from all the other planets. We have not room to detail the other arguments in support of this theory, which may be drawn from the position of the orbits of the comet and the two planets.

Comet of 1811.

A very large and interesting comet appeared in the year 1811, and reached its perihelion on the 12th September. M. Schroeter found the apparent diameter of its nucleus to be 1′ 49″, or 10,960 geographic miles. In the centre of this nucleus, he distinguished another nucleus, smaller and more luminous, the apparent diameter of which was 16″.97, or 1,697 miles. This central part was surrounded with a particular kind of atmosphere, and also with a luminous nebulosity. The total apparent diameter of the head of the comet was

34′ 12″, or 2,052,000 miles. The greatest apparent length of the tail was 18°, or 131,852,000 miles.

Comet of 1819. A remarkable comet was discovered at Marseilles by M. Pons, on the 26th November 1818, in the constellation Pegasus. It had a diameter of 5 or 6 minutes, and was easily seen through a night telescope. As the parabolic orbit computed for it by M. Bouvard did not represent the observations with sufficient accuracy, M. Enke tried an elliptical orbit, and found that it reduced the error from 3′ to 30″. According to this calculation, the period of this comet is only $3\frac{1}{4}$ years, and the larger axis of its orbit a little smaller than that of Vesta, so that it may be regarded as a body of our own system, which never ranges beyond the orbit of Jupiter.

Upon comparing its orbit with that of preceding comets, astronomers find that the comet which appeared in 1786, 1795, 1801, and 1805, must have been the same comet which re-appeared in 1818–19.

This remarkable body approaches nearer Mercury than any of the other planets, and as it must cross the Earth's orbit more than 60 times in the course of a century, there may be a slight probability of some collision between these two bodies.

This comet will pass its perihelion on the 24th or 25th May 1822, the longitude of the perihelion from the mean equinox, on the 24th May, being $5^s\ 7°\ 12'\ 7''$, and the longitude of the ascending node $11^s\ 4°\ 23'\ 40''$. It will not be seen in Europe in the spring of 1822, as it will be too faint in comparison with the evening twilight, nor can we ascertain if it will be visible with powerful telescopes in December 1821 or January 1822. In the southern hemisphere, however, it will be visible as early as the 9th or 10th June 1822, and will be like a star of the fifth magnitude.

The elements of the greater number of comets that have been observed till the year 1820, amounting to 111, are contained in the following Table. The Arabic figures in the first column accompanying the Roman numerals, point out the comets that resemble one another. Thus, the number 19 opposite to the year 1532 shews that the comet of that year is the same as the comet No. XIX, which appeared in 1661.

It will appear from a comparison of the numbers in the Table,

1. That 24 comets have passed between the Sun and the orbit

of Mercury; 33 between the orbits of Mercury and Venus; 21 between the orbits of Venus and the Earth; 16 between the orbits of the Earth and Mars; 3 between the orbits of Mars and Ceres; and 1 between the orbits of Ceres and Jupiter. 2. That 32 comets have appeared between the months of April and September, and 66 between September and April. 3. That the greater part of the comets have their perihelion nearest to their ascending nodes. 4 That 50 of the comets move from west to east, and not in the opposite direction. 5. That the orbits of the comets are not confined to any particular region of the heavens, like the old planets, but seem to be inclined at every possible angle to the ecliptic. This will appear from the following Table, which shews the number of comets whose inclinations are below every tenth degree.

Inclination of the Orbits of the Comets	Number of Comets observed below every tenth Degree.	Number calculated upon the supposition that they are uniformly distributed.	Difference.
10°	8	$10\frac{8}{9}$	$+2\frac{8}{9}$
20	19	$21\frac{7}{9}$	$+2\frac{7}{9}$
30	26	$31\frac{6}{9}$	$+6\frac{6}{9}$
40	37	$43\frac{5}{9}$	$+6\frac{5}{9}$
50	47	$54\frac{4}{9}$	$+7\frac{4}{9}$
60	64	$65\frac{3}{9}$	$+1\frac{3}{9}$
70	80	$76\frac{2}{9}$	$-3\frac{7}{9}$
80	89	$87\frac{1}{9}$	$-1\frac{8}{9}$
90	98	98	0

Table of the Elements of One Hundred and Eleven Comets, which have been observed and calculated till the Year 1820.

Order of the Comets.	Years when they appeared.	Time when the Comets passed their Perihelion. Mean time at Greenwich				Distance of their Perihelion, that of the Earth being 1.
		Days.	h	′	″	
I,	837	1 March,				0.58
II,	1231	30 January,	7	12	39	0 9478
III,	1264	6 July,	7	50	39	0 445
		17 July,	6	0	39	0 41081
IV,	1299	31 March,	7	28	39	0 3179
V,	1301	22 Oct nearly,				0 457
VI,	1337	2 June,	6	24	39	0 40666
		1 June,	0	30	39	0 6445
49,	1456	8 June,	22	0	39	0 5855
VII,	1472	28 February,	22	22	39	0 54273
49,	1531	24 August,	21	17	39	0 56700
19,	1532	19 October,	22	11	39	0 50910
VIII,	1533	16 June,	19	29	39	0.2028
3,	1556	21 April,	20	2	39	0.46390
IX,	1577	26 October,	18	44	39	0 18342
X,	1580	28 November,	13	44	39	0.59553
XI,	1582	7 May,				0.23004
XII,	1585	7 Oct N. S.	19	19	39	1.09358
XIII,	1590	8 Feb. N. S.	3	44	30	0.57661
XIV,	1593	18 July, N. S.	13	38	39	0.08911
XV,	1596	8 August,	15	33	39	0.549115
49,	1607	26 October,	3	49	39	0.58680
XVI,	1618	17 August,	3	2	39	0 51298
XVII,	1618	8 November,	12	22	39	0 37975
XVIII,	1652	12 November,	15	39	39	0.84750
XIX,	1661	26 January,	23	40	39	0 44851
XX,	1664	4 December,	11	51	39	1 025755
XXI,	1665	24 April,	5	14	39	0 10649
XXII,	1572	1 March,	8	36	39	0 69739
XXIII,	1677	6 May,	0	36	39	0.28059
XXIV,	1678	26 August,	14	2	39	1.23801
XXV,	1680	18 December,	0	[illegible]	[illegible]	0.006030
49,	1682	14 September,	7	38	39	0 58328
XXVI,	1683	13 July,	2	40	39	0.56020
XXVII,	1684	8 June,	10	15	39	0.96015

TABLE of the Elements of One Hundred and Eleven Comets, which have been observed and calculated till the Year 1820.

Years when they appeared	Direction of their Motion	Longitude of their Ascending Nodes				Place of their Perihelion.				Inclination of their Orbits to the Ecliptic		
		s	°	′	″	s	°	′	″	°	′	″
837	Retrog	6	26	33	0	9	19	3	0	10	0	12
1231	Direct,	0	13	30	0	4	14	48	0	6	5	0
1264	Direct,	5	19	0	0	9	21	0	0	36	30	0
	Direct,	5	28	45	0	9	5	45	0	30	25	0
1299	Retrog	3	17	8	0	0	3	20	0	68	57	0
1301	Retrog.	0	15	nearly		9	0	10	0	70	nearly.	
1337	Retrog	2	24	21	0	1	7	59	0	32	11	0
	Retrog	2	6	22	0	0	20	0	0	32	11	0
1456	Retrog	1	18	30	0	10	1	0	0	17	56	0
1472	Retrog.	9	11	46	20	1	15	33	30	5	20	0
1531	Retrog	1	19	25	0	10	1	39	0	17	56	0
1532	Direct,	2	20	27	0	3	21	37	0	32	36	0
1533	Retrog	4	5	44	0	4	27	16	0	55	49	0
1556	Direct,	5	25	42	0	9	8	50	0	32	6	30
1577	Retrog	0	25	52	0	4	9	22	0	74	32	45
1580	Direct,	0	19	7	37	3	19	11	55	64	51	50
1582	Retrog	7	0	0	21	8	5 or 9	11		59	or	61
1585	Direct,	1	7	42	30	0	8	51	0	6	4	0
1590	Retrog	5	15	30	10	7	6	51	30	29	40	40
1593	Direct,	5	11	14	0	5	26	19	0	87	58	0
1596	Retrog.	10	15	36	50	7	28	30	50	52	9	45
1607	Retrog.	1	20	21	0	10	2	16	0	17	2	0
1618	Direct,	9	23	25	0	10	18	20	0	21	28	0
1618	Direct,	2	16	1	0	0	2	14	0	37	34	0
1652	Direct,	2	28	10	0	0	28	18	40	79	28	0
1661	Direct,	2	22	30	30	3	25	58	40	32	35	50
1664	Retrog	2	21	14	0	4	10	41	5	21	18	30
1665	Retrog	7	18	2	0	2	11	54	30	76	5	0
1672	Direct,	9	27	30	30	1	16	59	30	83	22	10
1677	Retrog.	7	26	49	10	4	17	37	5	79	3	15
1678	Direct,	5	11	40	0	10	27	46	0	3	4	20
1680	Direct,	9	1	57	13	8	22	40	10	61	22	55
1682	Retrog.	1	21	16	30	10	2	52	45	17	56	0
1683	Retrog	5	23	23	0	2	25	29	30	83	11	0
1684	Direct,	8	28	15	0	7	28	52	0	65	48	40

Table of the Elements of Comets,—continued.

Order of the Comets.	Years when they appeared	Time when the Comets passed their Perihelion. Mean time at Greenwich.				Distance of their Perihelion, that of the Earth being 1.
		Days.	h	′	″	
XXVIII,	1686	16 September,	14	32	39	0.32500
XXIX,	1689	1 December,	14	55	39	0.016889
XXX,	1698	18 October,	16	56	39	0.69129
XXXI,	1699	13 January,	8	22	39	0.75435
XXXII,	1702	13 March,	14	12	39	0 64590
XXXIII,	1706	30 January,	4	55	39	0 426865
XXXIV,	1707	11 December,	23	43	36	0 85904
XXXV,	1718	15 January,	1	15	15	1.02565
XXXVI,	1723	27 September,	16	10	39	0.99865
XXXVII,	1729	25 June,	11	6	39	4.26140
		23 June,	6	36	1	4.0698
XXXVIII,	1737	30 January,	8	20	39	0.22282
XXXIX,	1739	17 June,	9	59	39	0.67358
XL,	1742	8 February,	4	38	39	0.76568
		8 February,	4	21	9	0.765555
XLI,	1743	10 January,	20	25	39	0.83501
		10 January,	21	15	36	0.838115
XLII,	1743	20 September,	21	16	39	0.52157
XLIII,	1744	1 March,	8	16	59	0 22206
XLIV,	1746	3 Mar. 1747,	7	10	39	2.19851
XLV,	1748	28 April,	19	25	24	0.84067
XLVI,	1748	18 June,	1	23	39	0.65525
XLVII,	1757	21 October,	9	46	39	0.3380
XLVIII,	1758	11 June,	3	17	39	0.21535
XLIX,	1759	12 March,	13	31	39	0.58349
		12 March,	13	50	3	0.58490
		12 March,	12	48	15	0.58360
L,	1760	27 Nov 1759,	0	2	36	0.80139
LI,	1760	16 Dec. 1759,	21	3	39	0.96599
LII,	1762	28 May,	15	17	39	1.0124
		28 May,	6	51	28	1.009856
		29 May,	0	18	27	1.01415
LIII,	1763	1 November,	19	43	17	0.49876
LIV,	1764	12 February,	13	42	15	0.55522
LV,	1766	17 February,	8	40	39	0.50538
LVI,	1766	22 April,	20	46	19	0.33274
LVII,	1769	7 October,	12	20	39	0.12376
		7 October,	13	36	52	0.12272

Table of the Elements of Comets,—continued.

Years when they appeared.	Direction of their motion.	Longitude of their Ascending Nodes.				Place of their Perihelion.				Inclination of their Orbits to the Ecliptic.		
		s	°	′	″	s	°	′	″	°	′	″
1686	Direct,	11	20	34	40	2	17	0	30	31	21	40
1689	Retrog.	10	23	45	20	8	23	44	45	69	17	0
1698	Retrog.	8	27	44	15	9	0	51	15	11	46	0
1699	Retrog	10	21	45	35	7	2	31	6	69	20	0
1702	Direct,	6	9	25	15	4	18	41	3	4	30	0
1706	Direct,	0	13	11	23	2	12	36	25	55	14	5
1707	Direct,	1	22	50	29	2	19	58	9	88	37	40
1718	Retrog	4	7	55	20	4	1	26	36	31	12	53
1723	Retrog	0	14	16	0	1	12	52	20	49	59	0
1729	Direct,	10	10	32	37	10	22	40	0	76	58	4
	Direct,	10	10	35	15	10	22	16	53	77	1	58
1737	Direct,	7	16	22	0	10	25	55	0	18	20	45
1739	Retrog	6	27	25	14	3	12	38	40	55	42	44
1742	Retrog.	6	5	38	29	7	7	35	13	66	59	14
	Retrog.	6	5	34	45	7	7	33	14	67	4	11
1743	Direct,	2	8	21	15	3	2	41	45	2	19	33
		2	8	10	48	3	2	58	4	2	15	50
1743	Retrog.	0	5	16	25	8	6	33	52	45	48	20
1744	Direct,	1	15	45	20	6	17	12	55	47	8	36
1746	Retrog.	4	27	18	50	9	7	2	0	79	6	20
1748	Retrog.	7	22	52	16	7	5	0	50	85	26	57
1748	Direct,	1	4	39	43	9	6	9	24	56	59	3
1757	Direct,	7	4	4	0	4	2	49	0	12	48	0
1758	Direct,	7	20	50	0	8	27	38	0	68	19	0
1759	Retrog.	1	23	49	0	10	3	16	0	17	39	0
	Retrog.	1	23	45	35	10	3	8	10	17	40	14
	Retrog	1	23	49	21	10	3	16	20	17	35	20
1760		4	19	39	41	1	23	34	19	79	6	38
1760	Retrog.	2	19	50	45	4	18	24	35	4	51	32
1762	Direct,	11	19	20	0	3	15	15	0	84	45	0
	Direct,	11	19	2	22	3	14	29	46	85	3	2
	Direct,	11	18	55	31	3	15	22	23	85	22	21
1763	Direct,	11	26	23	26	2	24	51	51	72	40	40
1764	Retrog.	4	0	4	33	0	15	11	52	52	53	31
1766	Retrog.	8	4	10	50	4	23	15	25	40	50	20
1766	Direct,	2	14	22	50	8	2	17	53	11	8	4
1769	Direct,	5	25	0	43	2	24	5	54	40	37	33
	Direct,	5	25	6	33	4	24	11	7	40	48	49

Table of the Elements of Comets,—continued.

Order of the Comets.	Years when they appeared.	Time when the Comets passed their Perihelion. Mean time at Greenwich. Days.				Distance of their Perihelion, that of the Earth being 1.
LVIII,	1770	14 August,	0	4	3	0.676893
		13 August,	12	55	39	0.674581
LIX,	1771	22 Nov. 1770,	5	38	39	0.52824
LX,	1771	18 April,	22	5	6	0.90576
LXI,	1772	18 February,	20	41	14	1.01815
LXII,	1773	5 September,	11	9	24	1.1339
LXIII,	1774	15 August,	10	46	14	1.4286
	1779	4 January,	2	2	39	0.71312
LXIV,		4 January,	2	15	9	0.7132
LXV,	1780	30 September,	18	3	29	0.09925
LXVI,	1781	7 July,	4	31	59	0.775861
LXVII,	1781	29 November,	12	32	25	0.96101
LXVIII,	1783	15 November,	5	44	2	1.5653
LXIX,	1784	21 January,	4	47	39	0.70786
LXX,	1784	9 April,	21	7	25	0 650531
LXXI,	1785	27 January,	7	48	43	1 143398
LXXII,	1785	8 April,	8	58	51	0.427300
LXXIII,	1786	7 July,	21	50	51	0.41010
LXXIV,	1787	10 May,	19	48	39	0.34891
LXXV,	1788	10 November,	7	25	39	1.06301
LXXVI,	1788	20 November,	9	4	24	0.766911
LXXVII,	1790	17 January,				0.75
		15 January,	5	5	39	0.75310
LXXVIII,	1790	28 January,	7	36	9	1.06329
LXXIX,	1790	21 May,	5	46	54	0.79796
LXXX,	1792	13 January,	13	34	52	1.29302
LXXXI,	1792	27 December,	7	47	6	0.96683
LXXXII,	1793	4 November,	20	11	39	0.4034
LXXXIII,	1793	18 November,	15	28	39	1.5045
LXXXIV,	1795	15 December,	8	20	29	0.24379
LXXXV,	1796	2 April,	19	45	45	1.57816
LXXXVI,	1797	9 July,	2	31	10	0.52661
LXXXVII,	1798	4 April,	11	58	16	0.48459
LXXXVIII,	1798	31 December,	21	55	44	0.77479
LXXXIX,	1799	7 September,	5	34	5	0.84018
		21 September,	4	25	0	0.82387
XC,	1799	25 December,	18	54	29	0.26688
XCI,	1801	8 August,	12	50	39	0.24[illegible]

Table of the Elements of Comets,—continued.

Years when they appeared.	Direction of their motion.	Longitude of their Ascending Nodes.				Place of their Perihelion.				Inclination of their Orbits to the Ecliptic.		
		s	°	′	″	s	°	′	″	°	′	″
1770	Direct,	4	12	17	3	11	26	26	13	1	34	30
	M.dist 3 148	4	12	0	0	11	26	16	26	1	33	40
1771	Retrog.	3	18	42	10	6	28	22	44	31	25	55
1771	Direct,	0	27	51	0	3	13	28	13	11	15	20
1772	Direct,	8	12	43	5	3	18	6	22	18	59	40
1773	Direct,	4	1	15	37	2	15	35	43	61	25	21
1774	Direct,	6	0	49	48	10	17	22	1	83	0	25
1779	Direct,	0	25	5	51	2	27	13	11	32	24	0
		0	25	3	57	2	27	13	10	32	25	30
1780	Retrog	4	4	9	19	8	6	21	18	53	48	5
1781	Direct,	2	23	0	38	7	29	11	25	81	43	26
1781	Retrog.	2	17	22	52	0	16	3	28	27	13	8
1783	Direct,	1	24	13	50	1	15	24	46	53	9	9
1784	Retrog.	1	26	49	21	2	22	14	24	51	9	12
1784	Retrog.	2	26	52	9	10	28	54	57	47	55	8
1785	Direct,	8	24	12	15	3	19	51	56	70	14	12
1785	Retrog.	2	4	33	36	9	27	29	33	87	31	54
1786	Direct,	6	14	22	40	5	9	25	36	50	54	28
1787	Retrog.	3	16	51	36	0	7	44	9	48	15	51
1788	Retrog.	5	7	10	38	3	9	8	27	12	28	20
1788	Direct,	11	21	42	15	0	23	12	22	64	52	32
1790	Retrog.	5	22	0	0	1	28	0	0	29	31	0
	Retrog.	5	26	11	46	2	0	14	32	31	54	15
1790	Direct,	8	27	8	37	3	21	44	37	56	58	13
1790	Retrog.	1	3	11	2	9	3	43	27	63	52	27
1792	Retrog	6	10	46	15	1	6	29	42	39	46	55
1792	Retrog.	9	13	14	44	4	15	52	35	49	7	18
1793	Retrog.	3	18	29	0	7	18	42	0	60	21	0
1793	Direct,	6	2	20	0	2	11	0	0	51	56	0
1795	Direct,	11	23	14	0	5	10	29	0	22	10	0
1796	Retrog.	0	17	2	16	6	12	44	13	64	54	38
1797	Retrog.	10	29	15	37	1	19	27	8	50	40	34
1798	Direct.	4	2	12	21	3	15	6	57	43	44	42
1798	Retrog.	8	9	30	2	1	3	35	5	42	14	52
1799	Retrog.	3	9	27	19	0	3	19	10	50	57	30
	Retrog.	3	9	34	0	0	3	36	0	50	52	30
1799	Retrog.	10	26	27	18	6	10	14	52	77	0	47
1801	Retrog.	1	12	8	0	6	1	1	0	20	20	0

TABLE of the Elements of Comets,—concluded

Order of the Comets.	Years when they appeared.	Time when the Comets passed their Perihelion. Mean time at Greenwich.				Distance of their Perihelion, that of the Earth being 1
		Days.	h	′	″	
XCII,	1802	9 September,	21	23	8	1.09411
XCIII,	1803	9 September,	20	33	54	1.0942
XCIV,	1804	13 February,	14	6	55	1.07117
XCV,	1805	16 November,	3	5	6	0.37862
XCVI,	1805	31 December,	6	12	40	0.89193
XCVII,	1806	28 December,	21	52	49	1.08193
XCVIII,	1807	18 September,	17	50	27	1.64648
XCIX,	1808	12 July,	4	1	33	0.60786
C,	1810	5 October,	19	44	55	0.96914
CI,	1811	12 Sept *	9	45	5	1.03568
CII,	1811	11 November,	4	21	1	1.5852
CIII,	1812	12 September,	14	8	0	0.78212
CIV,	1813	5 March,	16	36	44	0.67451
CV,	1813	19 May,	14	0	18	1.21433
CVI,	1815	26 April,	13	10	0	1.213
CVII,	1818	26 February,	26	0	0	1.19878
CVIII,	1818	5 December,	0	0	0	0.85643
CIX,	1819	27 January,	3	13	0	2.2131†
CX,	1819	28 June,	11	38	0	0.36247
CXI,	1819	26 June,	10	26	0	0.88117

* Upon the supposition of an elliptical orbit, M Bessel makes its period 3383 years M Flauguergues, who discovered this comet, thinks it is that of 1301. *See page* 231.

† Half the greater axis. *See page* 232.

TABLE of the Elements of Comets,—concluded.

Years when they appeared.	Direction of their motion.	Longitude of their Ascending Nodes.				Place of their Perihelion.				Inclination of their Orbits to the Ecliptic.		
		s	°	′	″	s	°	′	″	°		″
1802	Direct,	10	10	15	39	11	2	9	4	57	0	47
1803	Direct,	10	10	17	0	11	2	8	0	57	0	0
1804	Direct,	5	26	47	58	4	28	44	51	56	28	40
1805	Direct,	11	14	37	19	4	27	51	28	15	36	36
1805	Direct.	8	10	33	35	3	19	21	51	16	30	32
1806	Retrog.	10	22	18	37	3	4	1	30	35	4	5
1807	Direct,	8	26	46	3	9	0	5	0	63	10	35
1808	Direct,	0	24	11	15	8	12	58	50	39	18	59
1810	Direct,	10	8	53	4	2	3	9	10	62	46	17
1811	Retrog.	4	20	20	25	2	14	18	14	73	9	40
1811	Direct,	3	2	54	34	1	17	32	0	31	30	57
1812	Direct,	8	13	36	25	3	2	40	29	74	1	32
1813	Retrog.	2	17	27	30	2	6	52	30	27	33	30
1813	Retrog.	1	12	57	30	6	17	28	26	80	44	20
1815	Direct,	2	23	26	50	4	29	2	58	44	30	45
1818	Direct,	2	10	21	10	6	2	56	52	89	47	27
1818	Retrog.	2	19	55	14	3	11	46	58	63	10	30
1819	Direct,	11	4	35	0	5	6	59	15	13	37	0
1819	Direct,	9	3	53	40	9	20	47	59	80	7	41
1819	Direct,	3	17	46	0	8	15	51	0	8	26	0.

In a table of 116 comets arranged by De Lambre, in the order of their perihelion distances, he has noticed that there is

only 1 whose perihelion distance exceeds......4
2 which exceed 2
6 .... 1.5
23 .... 1.
31 ....0.7
39 .... 0.8
49 ....0.7
61 .... 0.6
83 .... 0.5
93 .... 0.4
104 .... 0.3
110 .... 0.2
113 .... 0.1

CHAP. XI.

ON THE FIXED STARS.

In the twentieth chapter of volume I, Mr. Ferguson has given some account of the number, distance, and arrangement of the fixed stars; and has mentioned a few of the nebulæ and variable stars, which had been discovered at the time when he wrote. This interesting branch of astronomy, however, was then but in its infancy. The positions of individual stars had been accurately determined, their immense distance had been fully ascertained, and a small number of variable, cloudy, and double stars had been discovered in different parts of the heavens: but no rational opinion had been formed respecting the structure of the starry firmament; the proper motions of the stars had not then been accounted for by the advancement of the solar system in absolute space; the double periods of some variable stars had not been ascertained; the theory of double stars, or binary sidereal systems, in which one star revolves round another, and the explanation of the milky way as the nebula in which our system is placed, had not, at that time, been given to the world. For the greater part of these discoveries we are indebted to the industry and genius of Dr. Herschel, who has also discovered and determined the position of several thousand nebulæ and double stars. In attempting to give a full account of these interesting and sublime discoveries, we shall adopt the arrangement of Dr. Herschel, after we have given some account of the distance, parallax, and proper motion of the stars, and of the phenomena of new and variable stars.

1. *Of the Magnitude, Distance, and Parallax of the Fixed Stars.*

On the appearance of the fixed stars.

When the fixed stars are viewed through a good telescope, their diameter appears much less than when they are examined by the naked eye. If we employ a telescope of still greater power, the apparent diameter will be increased, but not according to any regular progression. Even when seen, with the same power. in different telescopes, their apparent magnitude is not the same. Dr. Herschel always found that their diameter was less in pro-

portion the higher were the powers that he applied; and the smallest proportional diameter that he ever obtained was when he employed the extraordinary power of 6,450 times. The appearance of α, Lyræ, according to this astronomer, when viewed with a power of 160, is shewn at A in Plate V, *Sup.* Fig. 6, and at B, when seen with a power of 6,450. From these observations it appears that the apparent diameters of the fixed stars do not arise from any sensible disc, but from other causes with which we are not yet acquainted. This circumstance, therefore, might, of itself, be considered as a striking proof of the immeasurable distance of these celestial bodies, even though we had not been in possession of more convincing evidence.

Parallax of the stars.

The diameter of the Earth being too small a base for measuring any changes in the position of the fixed stars, astronomers have endeavoured to discover these changes by observing the position of the stars, when viewed from the Earth in two opposite points of its orbit; or, in other words, to find the *annual parallax* of the stars, or the angle subtended at any of them by the diameter of the Earth's orbit. Thus, when we view the star S, Plate V, *Sup.* Fig. 1, when the Earth is at E, we should expect it to appear in a different part of the heavens than when it is seen from the Earth at F. The observations made by Tycho, Picard, Hook, and Flamstead, to discover this annual parallax, were completely ineffectual; and even Dr. Bradley, the most accurate observer of the last century, ventures to affirm that the annual parallax of γ, Draconis, and η, Ursæ Majoris, does not amount to 2 seconds; and that, from the number of observations which he made, it could not amount even to 1 second.

Bradley's method of finding the annual parallax.

The method employed for this purpose by Bradley and other astronomers consisted in observing the meridian altitudes of the stars when the Earth was in opposite points of its orbit. The meridian altitudes were then corrected by refraction, aberration, and nutation, and the difference in the place of the stars, if any existed, was readily ascertained. This method, however, is obviously attended with great disadvantages, as the result is liable to be affected by variations in the atmospherical refraction, and also by any error in the aberration and nutation employed. On this account, Dr. Herschel has proposed a new method, greatly superior to the former, both in simplicity and accuracy, and

free of all errors arising from refraction, aberration, nutation, precession of the equinoxes, or any changes in the obliquity of the ecliptic.

Dr. Herschel's method.

The method of Dr. Herschel consists in measuring the variation in the distance between the two stars which compose a double star, when there is a considerable difference in their magnitude. Thus, let A, B, Plate VI, *Sup.* Fig. 1, be two opposite points in the Earth's orbit, and *x*, *y*, two stars of unequal magnitude, of which *x* is the greatest, and, therefore, probably the nearest; let the angle *x* A *y*, or the apparent distance of the stars, be measured when the Earth is at A, and the angle *x* B *y*, when the Earth is at B, and from the difference of these angles the parallax of the Earth's annual orbit may be easily deduced, upon the supposition that the distance of the stars is proportional to their magnitudes. When the two stars are within a few seconds of each other, it is manifest that their distance cannot be sensibly altered by any variations in the refraction of the atmosphere, or by any error in their aberration; and, therefore, a double star should be chosen in which the distance between its two component stars is very small. If the star *y* had been nearly of the same magnitude with *x*, its position would have been somewhere about *z*, at nearly the same distance from the Earth; so that the angular distance of the two stars would only have been *x* B *z*, when seen from B, which is much less than the angle *x* B *y*, when the star *y* is small, and, consequently, at a much greater distance from B.

This method, ingenious as it is, does not seem to have led Dr. Herschel to any accurate results respecting the parallax of the stars. The numerous observations which he has made on double stars seem rather to indicate that the smaller of the two performs a revolution round the greater; and that a variation in their distance may arise from another cause than the annual motion of the Earth. Dr. Brinkley of Dublin has very recently (*Phil. Trans.* 1810, Part II.) found a parallax of $2\frac{1}{2}$ seconds for α, Lyræ; but we are informed by Mr. Goombridge, that this result is not conformable to the numerous observations which he has made on that star.[1]

[1] Dr. Brinkley has recently obtained the following results respecting the parallax of the fixed stars:—

It appears, therefore, from all the observations that have yet been made, that, though the parallax of the fixed stars is completely undetermined, it can scarcely exceed a single second. A conclusion similar to this has been obtained by the late reverend Mr. Michell, from considering merely the quantity of light which they emit, and the peculiar circumstances of their situation. In this investigation, Mr. Michell supposes the stars to be, at a medium, equal to our Sun in magnitude and natural brightness; and that Saturn, exclusive of his ring, emits as much light as the most luminous fixed star. Now, the distance of Saturn being 2,082 of the Sun's semi-diameters, the density of the Sun's light at Saturn will be less than at his own surface, in the proportion of the square of 2,082 to 1, or in the proportion of 4,334,724 to 1. But the diameter of Saturn is only the 105th part of that of the ; and, therefore, the light which he emits must be diminished in the proportion of the square of 105 to 1, or as 11,025 to 10. By multiplying these numbers together, we shall find that the whole light of the Sun is to that of Saturn as 48,400,000,000 to 1, or as the square of 220,000 to 1; consequently, if the Sun were removed to 220,000 times his present distance, he would still appear as bright as Saturn, and the parallax of the Earth's annual orbit would be less than two seconds. But we have supposed that Saturn reflects all the light which falls upon him, which is very far from being the case. It is probable that one-fourth or one-sixth part of it is absorbed; and, therefore, we must increase the distance already computed in the ratio of 2 or $2\frac{1}{2}$ to 1, which would make the parallax of Saturn, when removed to that distance, less than 1 second. Upon the supposition, therefore, that the light of Saturn is equal to that of the brightest fixed star, and that the magnitude of this star is equal to that of the Sun, its annual parallax ought to be less than *one second.*

If we suppose, that the parallax of the nearest fixed is 1″, and that the mean distance of the Earth from the Sun is 95,000,000 miles, we shall have a right angled

Distance of the stars.

	Parallax.	No. of Observations.
α Cygni, -	1″56	119
α Aquilæ,	5″00	208
α Lyræ,	1′ 32	262

See *Irish Transactions*, vol. xii, and *Phil. Trans.* 1818, p 291, &c.

Our able astronomer royal, Mr. Pond, has obtained results quite hostile to the idea of a parallax. See *Phil. Trans.* 1818, p. 477, 481.

triangle, whose vertical angle is 1″, and whose base is 95,000,000 miles; to find its side, or the distance of the star, which will be 20,159,665,000,000 miles, or 20 billions of miles, a distance through which light could not travel in less than three years. If the brightest star in the heavens is placed at such an immense distance from our system, what an immeasurable interval must lie between us and those minute stars, whose light is scarcely visible in the most powerful telescope! Some of them, perhaps, are so remote, that the first beam of light which they sent forth at their creation has not yet arrived within the limits of our system; while other stars which have disappeared, or have been destroyed for many centuries, will continue to shine in the heavens till the last ray which they emitted has reached our Earth.

2. *On the Proper Motion of the Fixed Stars.*

On the proper motions of the stars.

In the fourth supplementary chapter of this volume, p. 153, &c. we have already stated, that the solar system is advancing towards the constellation Hercules. From this motion of the system in absolute space, it is obvious, that the stars in that constellation must appear to recede from each other; that those in the opposite part of the heavens must appear to approach; and that the intermediate stars must have motions corresponding to their situation, with regard to the direction in which the system moves; in the same manner as, when walking through a forest, the trees to which we advance are constantly widening, while the distance of those which we leave behind is gradually contracting. This motion of the fixed stars, from which the advancement of the solar system has been deduced, is called their *proper motion*. It was first observed by Halley, and afterwards by Lemonnier and Cassini. Tobias Mayer had the merit of giving the first explanation of this proper motion; but it was reserved for Dr. Herschel to point out the quarter of the heavens to which the solar system was advancing.

The following table contains the proper motion of 36 of the principal fixed stars in right ascension and declination, according to the accurate observations of Dr. Maskelyne.[2]

[2] In this volume, p. 102, the reader will find the annual variation in R. Ascension and north polar distance of 95 stars that are capable of being eclipsed by the Moon.

Table of the Annual Proper Motion of 36 Stars in Right Ascension and Declination.

Names of the Stars.	Magnitude.	Annual proper motion in right ascension. Seconds.	Annual proper motion in declination. Seconds.
		"	"
γ Pegasi	2	—0.09	—0.15 N.
α Arietis	2.3	+0.10	+0.07 S.
α Ceti	2	—0.12	—0.08 N.
Aldebaran	1	+0.03	+0.12 S.
Capella	1	+0.21	+0.44 S.
Rigel	1	—0.03	—0.16 N.
β Tauri	2	+0.01	+0.10 S.
α Orion	1	+0.01	—0.13 N.
Sirius	1	—0.42	+1.04 S.
Castor	2	—0.15	+0.44 S.
Procyon	1.2	—0.80	+0.95 S.
Pollux	2	—0.74	0.00
α Hydræ	2	—0.09	—0.14 N.
Regulus	1	—0.22	—0.08 N.
β Leonis	1.2	—0.57	+0.07 S.
β Virginis	3	+0.74	+0.24 S.
Spica Virginis	1	—0.02	—0.19 N.
Arcturus	1	—1.26	+1.72 S.
1 α Libræ	6	—0.11	—0.18 N.
2 α Libræ	2	—0.11	—0.15 N.
α Cor. Bor.	2.3	—0.26	+0.03 S.
α Serpentis	2	+0.11	—0.19 N.
Antares	1	0.00	—0.26 N.
α Herculis	2	0.00	—0.23 N.
α Ophiuchi	2	+0.06	+0.05 S.
α Lyræ	1	+0.23	—0.27 N.
γ Aquilæ	3	—0.11	—0.16 N.
α Aquilæ	1.2	+0.48	—0.54 N.
β Aquilæ	3.4	—0.03	+0.35 S.
1, α Capricorni	3	0.00	—0.28 N.
2, α Capricorni	3	+0.05	—0.26 N.
α Cygni	1.2	—0.08	—0.03 N.
α Aquarii	3	—0.08	—0.19 N.
Fomalhaut	1.2	+0.35	—0.06 N.
α Pegasi	2	—0.06	—0.18 N.
α Andromedæ	2	+0.08	+0.06 S.

In the following Table we have given the proper motion of 9 principal fixed stars in longitude and latitude, according to the most recent observations of Dr. Maskelyne, including the precession, &c.

Names of the Stars.	Annual increase of Longitude.	Annual variation of Latitude.
	"	"
α Arietis	50.271	+0.180
Aldebaran	50.204	—0.317
Pollux	49.470	+0.280
Regulus	50.004	+0.200
Spica Virginis . . .	50.059	+0.080
Antares	50.141	+0.167
α Aquilæ	50.870	+0.372
Fomalhaut	50.717	+0.013
α Pegasi	50.133	+0.163

3. *On New and Variable Stars.*

On variable stars.

While the apparent places of the fixed stars are thus constantly changing, many of the stars themselves seem to be affected with variations of a different kind, arising either from some peculiarities in their physical constitution, or from some great changes going on upon their surface. Several stars have appeared in the heavens for a while, and then vanished. Several, whose positions are given in the ancient catalogues, can no longer be discovered, even by the powerful instruments of modern astronomers; while others are distinctly visible, which do not appear to have been observed by the ancients. A few stars have gradually increased in brilliancy; some that have been formerly variable, now shine with a steady light; others have been constantly diminishing in brightness; and a considerable number sustain a periodical variation in their lustre. The new star of 1572, which Tycho observed in the constellation Cassiopeia, exhibited very singular changes. Its brightness suddenly became so great, that it exceeded that of Venus and Mercury, and was visible on the meridian during the day. The intensity of its light gradually diminished, and it disappeared sixteen months after its first appearance. The new star in the constellation Serpentarius, which was seen in 1603, exhibited phenomena nearly similar, and vanished, after having been visible for some months.

Theory of variable stars.

Astronomers have attempted to explain these remarkable changes, by supposing, that portions of the surface of the stars are covered with large black spots, which, during the diurnal rotation of the star, present themselves under various angles, and thus produce a gradual variation in its brilliancy. These spots have been regarded by some as permanent; while others are of opinion, that the luminous surface of the stars is subject to perpetual changes, which sometimes increase their light, and at other times extinguish it. M Maupertuis (See Vol. I, p. 312, *Note.*) has explained these phenomena with less plausibility, by supposing, that in consequence of a rapid rotation about their axes, the stars are reduced to flat circular planes, like millstones; and that the inclination of their axes may be varied by the attraction of their surrounding planets. Hence, stars of this form will appear more or less brilliant according to the inclination of their flat side to the eye of the observer. The periodical variation in the light of the stars has also been ascribed to the interposition of the planets which circulate around them; but it is by no means probable, that these planets, even if they do exist, are sufficiently large to obstruct any large portion of their light. Even when seen from the Earth, the light of our own Sun is not sensibly impaired when Mercury and Venus are passing over his disc.

Pigott's theory of the variable star in Sobieski's Shield.

The ingenious Mr. Pigott has ventured a step farther than any of his predecessors in this branch of astronomy. In his investigation of the phenomena exhibited by the variable star of Sobieski's shield, the periodical changes of which are affected by very singular anomalies, he supposes, that the greater part of its disc is unenlightened; and that a few luminous spots, placed at certain intervals, produce, by the rotation of the star, all the variations which have been observed. Mr. Pigott supposes, that the body of the stars is dark and solid; that their rotation on their axes is regular; and that the surrounding medium is occasionally generating and absorbing its luminous particles, by a process similar to what Dr. Herschel supposes is going on in the atmosphere of the Sun. He imagines, that these luminous particles are sparingly dispersed in the atmosphere of the variable star of Sobieski, from the circumstance of its diminishing, even to the 9th magnitude; and as the duration of its full lustre continues only about 9½ days, while it performs a complete ro-

tation in 62 days, he considers the luminous spots to be somewhat circular, and of no great extent. Since this small portion of light may naturally be supposed to diminish and finally disappear, Mr. Pigott imagines, that this may have been the cause of the disappearance of the new stars of 1572 and 1604. Hence, he concludes, that there are others which have never shewn a glimpse of brightness; and that there are 'primary invisible 'bodies, or unenlightened stars, that have ever remained in 'eternal darkness.' Following out this notion, Mr. Pigott conceives, that clusters of these dark bodies may be found, and, by intercepting 'all more distant rays,' may appear like dark spaces in the heavens, similar to what has been observed in the southern hemisphere.

The number of stars which are ascertained to be variable, amounts only to 15; while those which are suspected to be variable, amount to 37. With an account of their positions and variations we shall conclude this section.

I. STARS ASCERTAINED TO BE VARIABLE.

1. *New Star of 1572 in Cassiopeia.*

R. Asc. 1786, 0^h 13′ 0″. Decl. N. 62° 58′. Greatest and least mag. 1—0. Period 150 years.

The period of this star is merely a conjecture of Keill and other astronomers. It did not appear at the end of this period; but this might arise from its having, like other variable stars, different degrees of lustre at different periods.

2. *ο in the Whale.*

R. Asc. 1786, 2^h 8′ 33″. Decl. S. 3° 57′ 25″. Greatest and least mag. 2—0. Period 334 days.

This period was determined by Cassini. Mr. Goodricke saw this star of the 2d magnitude on the 9th August 1782; and on December 30, 1782, Pigott saw it of the 8.9th magnitude. Dr. Herschel makes its period 331^d 10^h 19′.

3. *Algol, or β Perseus.*

R. Asc. 1786, 2^h 54″ 19″. Decl. N. 40° 6′ 55″. Greatest and least mag. 2—4. Period 2^d 20^h 48′ 58″.7.

This period was determined by Wurm from 15 years' observation. Montanari first observed the variations of this star. Maraldi, in 1693, could not perceive any change in its brightness: but in 1694, he found that it varied from the second to the fourth magnitude. Mr. Goodricke of York was the first who discovered its period, which he found to be 2ᵈ 20ʰ 48′ 56″. He found that its brightness, when at its *minimum*, is different in different periods; and Pigott is of opinion, that, at its *maximum* brightness, it is sometimes more luminous than α, Persei, and at other times less brilliant.

4. *420th Star in Mayer's Catalogue situated in the Lion.*

R. A c. 1786, 9ʰ 36′ 5″. Decl. N. 2° 25′ 0″. Greatest and least mag. 6—0.

This star was discovered to be variable by M. Koch. In February 1782, he found No. 419, and No. 420, of the same magnitude, and therefore of the 7th. In April 1783, it appeared of the 9th magnitude, and in April 1784, of the 10th. Pigott could never see this star, so that it must have disappeared.

5. *Star in Hydra, as far east of π as ψ is west of γ: it is the 30th Hydra of Hevelius, and probably the 1st of the Balance, according to Flamstead.*

R. Asc. 1786, 13ʰ 18′ 4″. Decl. S. 22° 9′ 38″. Greatest and least mag. 4—0. Period 494 days.

Maraldi discovered this star to be variable in 1784, and made its period two years. According to Pigott, it is of the 4th magnitude when at its full brightness, and suffers no perceptible change for about a fortnight. It takes about six months to increase from the 10th to the 4th magnitude, and about the same time to return to the 10th; hence, it may be regarded as invisible to the naked eye during six months. The time of its increase is one-half quicker than the time of its decrease; and it does not always reach the same degree of brightness.

6. *New Star of 1604, in the east foot of Serpentarius.*

R. Asc. 17ʰ 18′ 0″. Decl. S. 21° 10′ 30″. Greatest and least mag. 1—0.

This star was seen by Kepler on the 17th October 1604, and exhibited almost the same phenomena as that of 1572. On the

3d January 1605 it began to diminish, and it ceased to be visible on the 18th October 1604, by the approach of the Sun, and has not even been seen, though Mr. Pigott has examined that part of the heavens with great care since 1782. Kepler has given a full account of it in his treatise *De Stella Nova in pede Serpentarii.*

7. β, *Lyræ.*

R. Asc. 18h 42′ 11″. Decl. N. 33° 7′ 46″. Greatest and least mag. 3—4.5. Period 6d 9h.

The variations and period of this star were discovered by Mr. Goodricke. The period is not accurately ascertained.

8. *New Star of* 1670, *in the Swan's head.*

R. Asc. 19h 38′ 58″. Decl. N. 26° 48′ 30″. Greatest and least mag. 3—0.

This star was discovered by Don Anthelme on the 20th June 1670. It soon reached the 3d magnitude, and disappeared, after several variations, in 1672. On the 10th August, it had decreased to the 5th magnitude, and was observed of the 6th magnitude by Hevelius, in the years 1671, 1672. Since that time it has not been seen, though Pigott believes that he could have detected it, had it reached even the 10th or the 11th magnitude. See *Phil. Trans.* No. 65.

9. ν, *Antinoi.*

R. Asc. 19h 41′ 34″. Decl. N. 0° 28′ 14″. Greatest and least mag. 3.4—5. Period 7d 4h 15′.

The variations and period of this star were discovered by Pigott. It continues 40 hours at its greatest brightness, 30 at its least, 66 on its decrease, and 36 on its increase. Its maximum and minimum brightness seem to be uniform.

10. χ *in the Swan's neck.*

R. Asc. 19h 42′ 21″. Decl. N. 32° 22′ 58″. Greatest and least mag. 5—0. Period 396d 21h.

The variation of this star was discovered by Kirch in 1686. Maraldi Cassini and M. Le Gentil made its period 405 days, from which circumstance Pigott concludes that its period is variable. According to Pigott, it continues a fortnight at its full brightness. It takes about 3½ months in increasing from

the 11th magnitude to its maximum brightness, and in decreasing to the 11th magnitude again. Hence it may be regarded as invisible for six months. When at its greatest brightness, it is sometimes of the 5th, and at other times of the 7th magnitude.

11. *Near γ, in the Swan's breast.*

R. Asc. $20^h\ 9'\ 54''$. Decl. N. $37^\circ\ 22'\ 37''$. Greatest and least mag. 3—0. Period 18 years.

This star was observed by Jansonius and Kepler in 1600. From the observations made in the 17th century, Pigott concludes that it continues about five years at its full brightness; that it decreases rapidly during two years; that it is invisible to the naked eye during four years; and that it increases slowly during seven years. At the end of the year 1663 it was at its minimum brightness. From November 1781 to 1786 Pigott always saw it of the 6th magnitude, though he suspects that in 1785–1786 it had rather decreased.

12. δ, *Cephei.*

R. Asc. $22^h\ 21'\ 0''$. Decl. N. $57^\circ\ 20'\ 0''$. Greatest and least mag. 4.3—4.5. Period $5^d\ 8^h$.

The variation and period of this star were discovered by Mr. Goodricke, and the period which he found has been confirmed by Mr. Pigott's observations. Its variations are not easily seen unless at its minimum and maximum brightness.

13. 64. *or* α, *Hercules.*

R. Asc. $17^h\ 4'\ 54''$. Decl. N. $14^\circ\ 38'$. Period of variation $60\frac{1}{4}$ days

The variation and period of this star were discovered by Dr. Herschel, by comparing it with κ Ophiuchi.

14. *A Star in Sobieski's Shield, having nearly the same right ascension as the Star* 1, *and situated about a degree farther south.*

R. Asc. in 1796, $18^h\ 36'\ 38''$. Decl. S. $5^\circ\ 56'$. Greatest and least mag. 5—7.8. Period 62 days.

The period and variations of this star were discovered by Mr. Pigott, who has endeavoured to exhibit, in the following Table, the result of two sets of observations, made at different periods.

	Observations of 1796.	Succeeding observations.	Mean results.
	Days.	Days.	Days.
Rotation on its axis,.........................	61½	62¼	62—
Duration of brightness at its maximum without any sensible change,............	8+	14	9½
Ditto when it does not reach its usual brightness,................................	20—	—	—
Duration of brightness at its minimum without any perceptible change,.........	9	9	9
Ditto when it does not reach its usual minimum,....................................	20—	—	—
Time employed in decreasing from the middle of its maximum to the middle of its minimum brightness,...............	31	28	33+
Time employed in increasing from the middle of its minimum to the middle of its maximum brightness,...................	27+	35	29—
	Mag.	Mag.	Mag.
Extremes of its different degrees of brightness, with a mean of its usual variations,....................................	5+ 9 or 0	5+ 7.8	5 6

The mean results in the last column are computed proportionally according to the number of observations from which the results in the preceding columns were obtained.

15. *Star in the Northern Crown, ranked of the sixth magnitude by Bayer, but omitted in Flamstead's catalogue.*

R. Asc. in 1796, 15^h 40′ 11″. Decl. N. 28° 49′ 30″. Greatest and least mag. 6.7—0. Period 10½ months.

Mr. Pigott suspected this star to be variable in 1783, and his suspicions were confirmed in the spring of 1795, when it was invisible. On the 20th of June of the same year he saw it of the 9.10 magnitude. In the space of six weeks afterwards, it had attained its full brightness, the middle time of which was the 11th August 1795. It was at that time of the 6.7 magnitude, and continued so for about three weeks. It then took 3½ weeks in decreasing to the 9.10 magnitude, and it disappeared a few days afterwards. In April 1796, it again appeared. On the 7th May it reached the 9.10 magnitude, and increased nearly in a similar manner as on the 20th June 1795. In a subsequent period, it exhibited great unsteadiness at its maximum brightness. It then increased as before, with tolerable regularity, till it reached the 7.8 magnitude, when it kept wavering between these two magnitudes till August 1797.

II. STARS SUPPOSED TO BE VARIABLE.

1. *Hevelius's 6 Cassiopeiæ.*

R. Asc. 0^h 23′ 16″. Decl. N. 60° 50′. Greatest and least mag. 7—0.

Mr. Pigott observed in 1782 that this star was missing; and he could not find it in 1783 and 1784.

2. 46, *or* ξ *Andromedæ.*

R. Asc. 1^h 9′ 46″. Decl. N. 44° 24′. Greatest and least mag. 4.5—5.6.

According to Mr. Pigott, this star was, in 1784 and 1785, less than υ, equal to ω, and brighter than *d* and χ. It is marked in his journal as sometimes brighter than ω, and at other times less bright. 46 and ξ Andromedæ seem to be different stars.

3. *Flamstead's* 50, *or* υ *Andromedæ.*

R. Asc. 1^h 24′ 16″. Decl. N. 40° 20′ 15″. Greatest and least mag. 4.5—0.

4. *Hevelius's* 41 *Andromedæ, which is probably the same with Tycho's* 19 *Andromedæ.*

Some of the stars beside the two preceding are said by Cassini to have disappeared and reappeared. In 1783, 1784, and 1785, Mr. Pigott observed their brightness to be as in the following table:—

Flamstead's 50, of the 4.5 magnitude, and perhaps rather less than φ Andromedæ.
——————— τ, of the 5th magnitude, and equal to 46 and 48 Andromedæ.
——————— 49 }
——————— 52 } Of the same brightness, and of the 5.6 magnitude.
Hevelius's 41 }

A star between Hevelius's 41 and Flamstead's 52 is rather less than the 6th magnitude.

5. *Tycho's 20 Ceti, probably* χ *in the Whale's Belly.*

R. Asc. 1^h 39′. Decl. S. 13° 20′. Greatest and least mag. 5—0.

This star had disappeared in the time of Hevelius. χ Ceti is of the 4.5 magnitude, and of the same brightness as the three ψ Aquarii.

6. *Flamstead's 55 Andromedæ, marked nebulous in his catalogue.*

R. Asc. 1h 40′ 30″. Decl. N. 39° 40′ 3″. Greatest and least mag. 6—0.

This star appears nebulous, in consequence of some small stars which are near it, but it is not really so. Pigott and Hevelius observed it to be a star of the 6th magnitude.

7. *σ, or the 17th Eridani, according to Ptolemy and Ulugh Beigh.*

R. Asc. 2h 42′. Decl. S. 9° 40′. Greatest and least mag. 4—0.

In 1691 and 1692, Flamstead could not see this star. In 1782, 1783, and 1784, Pigott observed in this place a star of the 7th magnitude, which did not exhibit any variation of brightness. It always appeared less than two little stars near and below η Eridani.

8. *Flamstead's 41 Tauri, the 26th of Ulugh Beigh, and the 43d of Tycho.*

R. Asc. 3h 53′ 27″. Decl. N. 27° 0′ 39″. Greatest and least mag. 5—8.

This star, which Cassini suspected, without much reason, to be new and variable, was seen by Ulugh Beigh and Tycho. In 1784 and 1785, Mr. Pigott found it of the 5th magnitude, equal to δ, and brighter than ψ, P, and χ Tauri. Hevelius makes it of the 5th, and Flamstead of the 6th magnitude.

9. *Star 2° 15′ north of 53 Eridani.*

R. Asc. 4h 29′. Decl. S. 12° 30′. Greatest and least mag. 4—0.

Cassini believed that this star was a new one, and was not visible in 1664. In 1784, Pigott observed it to be less than ω and *d*, brighter than A, and equal to ψ Eridani.

10. *Flamstead's 47 Eridani.*

R. Asc. 4h 23′ 54″. Decl. S. 8° 41′ 40″. Greatest and least mag. 4—0.

This star was also supposed by Cassini to be a new one. In 1784, it appeared to Mr. Pigott less than 46 Eridani.

11. *γ of the Great Dog.*

R. Asc. 6h 54′ 5″. Decl. S. 15° 19′ 36″ Greatest and least mag. 3—0.

Tycho, Bayer, Hevelius, and Flamstead, mark this star as of the 3d magnitude. It was invisible in 1670, according to Maraldi and Montanari; but in 1692 and 1693, it appeared of the 4th magnitude. Mr. Pigott has observed it frequently since 1782, but never perceived the least variation. It was always of the 4th magnitude, a little brighter than θ, and decidedly brighter than ι. La Caille also makes it of the 4th magnitude.

12. *Pollux, or β Gemini.*

R. Asc. 7h 32′ 11″. Decl. N. 28° 31′ 38″. Greatest and least mag. 1—3.

Mr. Pigott observes, that if either Castor or Pollux have varied in lustre, it is probably the latter. In the years 1783, 1784, and 1785, Pollux was undoubtedly brighter than Castor. Hevelius makes them both of the 2d magnitude. Flamstead makes Castor of the 1st, and Pollux of the 2d magnitude. La Caille makes Castor of the 1.2, and Pollux of the 2.3 magnitude, and Bradley makes them both of the 1st magnitude.

13. *ξ Leonis.*

R. Asc. 9h 20′ 4″. Decl. N. 12° 14′ 23″. Greatest and least mag. 5.6—0.

Tycho, Bayer, Flamstead, Mayer, and Bradley, have all marked this star of the 4th magnitude. It could scarcely be seen by Maraldi and Montanari in 1693. In 1783, 1784, and 1785, Pigott saw it always of the 5th magnitude, less than A and π, and perhaps rather brighter than *h* and ω Leonis.

14. *ψ Leonis.*

R. Asc. 9h 32′ 3″. Decl. N. 14° 59′ 36″. Greatest and least mag. 5.6—0.

This star is said to have disappeared in 1667, when it was seen by Montanari. Maraldi observed it in 1691, when it was very small. From 1784 to 1786, Pigott saw it always of the 5.6 magnitude, less than ω, and brighter than *i*, Flamstead's 46th. Hevelius makes it of the 5th, and Flamstead of the 6th magnitude.

15. *25 Leonis.*

R. Asc. 9h 46′ 8″. Decl. N. 12° 20′ 36″. Greatest and least mag. 6.7—0.

In 1783, Mr. Pigott discovered that this star was missing. He could not see it in 1784 and 1785.

16. *Bayer's i Leonis, and Tycho's* 16 *Leonis.*

R. Asc. 9^h 52′ 30″. Decl. N. 15° 30′. Greatest and least mag. 6—0.

This star was invisible in 1709; but near its place were perceived *eight* other stars, to be found in no catalogue. Pigott could not see it in 1785. It is not the *i* Leonis of other catalogues.

17. *δ Great Bear.*

R. Asc. 12^h 4′ 45″. Decl. N. 58° 13′ 24.″ Greatest and least mag. 2—4.

This star is marked of the 2d magnitude by Tycho and the Prince of Hesse, while Hevelius, La Caille, and Bradley, mark it of the 3d. From 1783 to 1786, it appeared to Pigott as a bright 4th magnitude, rather less than ι, equal to α, and rather brighter than κ Draconis. Flamstead marks it of the 2.3 magnitude.

18. *n Virginis.*

R. Asc. 12^h 7′ 43″. Decl. N. 0° 24′ 16″. Greatest and least mag. 6—0.

This star, which is not in the charts of Bayer, was observed by Ricciolus. Flamstead could not see it on the 27th of January 1680, though he must have observed it on the 12th May 1677, and some years afterwards, as it is in his catalogue. Mr. Pigott examined it frequently in 1784 and 1785; but it always appeared of the 6th magnitude, less than *c*, and rather brighter than a star three degrees lower, in a right line with *c* and *n* Virginis. Flamstead makes it of the 6th, and Bradley of the 5th magnitude.

19. *Bayer's Star of the 6th magnitude*, 1° *south of γ Virgin.*

R. Asc. 12^h 53′. Decl. S. 10°. Greatest and least mag. 6—0.

This star is the most southern of the two, χ and *q*, which are placed under the south hand of the Virgin by Bayer and Flamstead. Maraldi could not see it, and Pigott looked for it in vain in May 1785.

20. *Star in the Virgin's northern Thigh.*

R. Asc. 13^h 29′ +. Decl S. 0° 30′. Greatest and least mag. 6—0.

Ricciolus marks this star as of the 6th magnitude. Maraldi could not see it in 1709, and Pigott could not see it in 1785.

21. 91 *or* 92 *Virginis.*

R. Asc. $13^h\ 43'\ 43''$. Decl. N. $2°\ 5'\ 50''$. Greatest and least mag. 6—0.

In 1785, Pigott found one of these stars missing, which he supposed to be the 91. The remaining one is of the 6.7 magnitude.

22. *α Draconis.*

R. Asc. $13^h\ 58'\ 36''$. Decl. N. $65°\ 24'\ 8''$. Greatest and least mag. 2—4.

This star is at present only of the 4th magnitude, though Hevelius, Flamstead, and Bradley, mark it of the 3d. Mr. Pigott and Dr. Herschel both suppose it to be variable. The former, however, examined it frequently between October 1782 and 1786, but never perceived any change in its lustre. It was less than ι Draconis, equal to δ of the Great Bear, and rather brighter than κ Draconis. La Caille marks it of the 3d magnitude.

23. *Bayer's Star in the West Scales of Libra.*

R. Asc. $14^h\ 53'\ 30''$. Decl. S. $13°\ 26'$. Greatest and least mag. 4—7.

Maraldi could not find this star, and Pigott looked for it in vain in 1784 and 1785. In this place there are several small stars, of about the 8th magnitude, none of which, according to Pigott, are near as bright as the 2d ν Libræ.

24. *Ptolemy and Ulugh Beigh's No. 6 of the unformed Stars in Libra.*

R. Asc. $15^h\ 29'+$. Decl. S. $20°\ 30'$. Greatest and least mag. 4—7.

Though this star is marked of the 4th magnitude, it does not appear in any modern catalogue. In 1785, Mr. Pigott frequently observed a star of the 7th magnitude very near its place, rather less than Flamstead's 41.

25. *κ Libræ.*

R. Asc. $15^h\ 29'\ 39''$. Decl. S. $19°\ 58'\ 27''$. Greatest and least mag. 4—5.

Tycho and Bayer mark this star as of the 4th magnitude

Hevelius says that it had disappeared. During the years 1783, 1784, and 1785, Pigott found it always of the 5th magnitude, less than ψ or θ, equal to λ, and brighter than η. Flamstead marks it of the 4th magnitude.

26. *Tycho's* 11 *Libræ.*

R. Asc. $15^h\ 37'\ 30''$. Decl. S. 19° 30′. Greatest and least mag. 4—0.

Hevelius and Pigott could not find this star. The latter thinks that it never existed, and that it is the κ, with an error of 2° in longitude.

27. 33 *Serpentis.*

R. Asc. $15^h\ 38'$. Decl. N. 17° 14′. Greatest and least mag. 6—0.

In 1784, Pigott found that this star was missing, and he could not see it in 1785, with a night-glass.

28. *Bayer's Star, near* ε *of the Great Bear.*

R Asc. $16^h\ 15'$. Decl. N. 82° 45′. Greatest and least mag. 6—0.

This star could not be seen by Cassini. Pigott found no star near the ε brighter than the 7.8th magnitude.

29. ρ, *or Ptolemy and Ulugh Beigh's* 14*th of Ophiuchus, or Flamstead's* 36*th.*

R Asc. $17^h\ 2'\ 14''$. Decl. S. 26° 15′ 37″. Greatest and least mag 4—0.

This star is said to have disappeared before 1695. Hevelius could not find it. In 1784 and 1785, Pigott saw it of the 1.5 magnitude, much brighter than 39, rather brighter than 51 and 58, and less than 44. On the 30th June 1783, Pigott marked it in his journal as equal to 39, and less than 51 and 58.

30. *Ptolemy's* 13*th Ophiuchi.*

R. Asc. $17^h\ 18'+$. Decl. S. 20° 35′. Greatest and least mag. 4—0.

31. *Ptolemy's* 18*th Ophiuchi.*

R. Asc. $17^h\ 22'$. Decl. S. 24° 10′. Greatest and least mag. 5—0.

The two preceding stars seem to have disappeared. Mr. Pigott, however, thinks that the 13th Ophiuchi is Flamstead's 40th, and that the 18th Ophiuchi should be marked with north,

instead of south, latitude, which would make it coincide nearly with Flamstead's 58th.

32. *σ Sagittarii.*

R. Asc. 18h 42′. Decl. S. 26° 32′ 34″. Greatest and least mag. 2—4.

Dr. Herschel and Mr. Pigott agree in thinking this star variable. In 1783, 1784, and 1785, Pigott observed it of the 2.3 magnitude, and brighter than π Sagittarii. Hevelius makes it of the 4th, and La Caille of the 2.2 magnitude.

33. *θ Serpentis.*

R. Asc. 18h 45′ 35″. Decl. N. 3° 56′ 36″. Greatest and least mag. 4—5.

Tycho, Bayer, Hevelius, and Flamstead, observed this star to be of the 3d magnitude. Montanari saw it of the 5th, and found it to increase in the following year. In 1783, 1784, and 1785, Pigott observed it frequently without perceiving any change in its lustre. It was always of the 4th magnitude, less than δ Aquilæ, and P. Ophiuchi. La Caille makes it of the 4.3 magnitude.

34. *Tycho's 27 Capricorni.*

R. Asc. 21h 41′ 0″. Decl. S. 14° 28′ 0″. Greatest and least mag. 6—0.

This star could not be seen by Hevelius, nor by Pigott in 1778, 1782, and 1784, with his transit instrument.

35. *Tycho's 22 Andromedæ, at the end of the chain.*

R. Asc. 21h 43′ 30″. Decl. N. 49° 15′. Greatest and least mag. 4—0.

Cassini observes that this star was grown so small, that it could scarcely be seen. It should be near the two π Cygni, but Pigott could find no star in this place in 1784 and 1785.

36. *Tycho's 19th Aquarii.*

R. Asc. 22h 25′. Decl. S. 15° 55′ 0″. Greatest and least mag. 6—0.

Hevelius remarks that this star was missing, and that Flamstead could not see it with his naked eye. Pigott, who could not see it in 1782, is confident that it is the same as Flamstead's 56th, marked *f* by Bayer, from which it is only 1½° distant.

37. *ο Andromedæ.*

R. Asc. 22ʰ 52′ 6″. Decl. N. 41° 10′ 45″. Greatest and least mag. 4—6.

According to Pigott, this star is less than σ Cephei, equal to ζ Cassiopeiæ, or perhaps rather brighter than it, and brighter than λ, κ or ι Andromedæ.

38. *La Caille's* 483 *Aquarii.*

R. Asc. 22ʰ 55′ 40″. Decl. S. 8° 50′ 45″. Greatest and least mag. 7—0.

Mr. Pigott found this star missing in 1778, and he could not see it in 1783 or 1784

Stars supposed by Dr. Herschel to be lost.

The following 13 stars are ranked by Dr. Herschel among those that are lost, or have undergone some great change.

80 *and* 81 *Hercules.*

These stars, though of the 4th magnitude in Flamstead's catalogue, are not to be found.

71 *Hercules.*

This star is of the 5th magnitude in Flamstead's catalogue, but seems to be lost.

55 *Hercules.*

This star, which Dr. Herschel saw on the 12th April 1782, is now lost.

56 *Cancer.*

This star has vanished, though it is of the 6th magnitude. There is a telescopic star near its place.

19 *Perseus.*

This star of the 6th magnitude is lost.

108 *Pisces.*

This star of the 6th magnitude, near the head of Aries, is lost.

73 and 74 *Cancer.*

These two stars of the 6th magnitude, in the southern claw of the Crab, are either lost, or have suffered such great changes that they can no longer be found.

8 *Hydrae.*

This star is lost. A star just by it may be the 31st Unicorn. If this last should be the 8th Hydræ, and a small star near it the 31st Unicorn, their magnitudes and places have undergone a great change.

26 *Cancer.*

This star is lost.

62 *Orion.*

This star is lost, and a star near the 54th and 51st is not noticed by Flamstead.

34 *Berenice's Hair.*

This star of the 5th magnitude is lost.

19 *Berenice's Hair.*

This star is either lost, or has moved and changed its magnitude.

The following stars are ranked by Dr. Herschel among those that have changed their magnitude since the time of Flamstead.

Stars which Dr. Herschel supposes to have changed their magnitude.

α Draconis is much less than β, though Flamstead makes it smaller.

α Ceti is much less than β Ceti, though Flamstead makes the former of the second, and the latter of the 3d magnitude.

ζ Serpentis is less than η, though Flamstead makes them of the same magnitude.

η in the Swan is brighter than χ.

The 2 of the Great Bear is of the 5th, and not of the 6th magnitude.

η Bootes is much larger than ζ.

ι Dolphin is much larger than γ.

β Triangle is much larger than α.

γ Eagle is larger than β.

σ Sagittarius is larger than δ, γ, and ε, though marked as smaller.

δ of the Great Dog is larger than β.

η Serpent is much larger than ζ.

κ Serpentarius is larger than γ and ι.

β of the Little Horse is less than α.

δ Dolphin is larger than ϵ.

ϵ Bootes is larger than ζ.

δ in the Arrow is larger than α and β.

δ in the Great Bear is less than ϵ, ζ, or η. It is only of the 4th magnitude, while these three are at least of the 2.3.

α Great Bear is much less than any other star marked, like it, of the 1.2 magnitude.

The 1st and 2d Hydræ are only of the 8th or 9th magnitude, instead of the 4th, as they are marked by Flamstead.

γ Lyræ is much larger than β.

The 31st and 34th of the Dragon have changed greatly. The 31st has increased from the 7th to the 4th, and the 34th has diminished from the 4.5 to the 6.7 magnitude.

44 Cancer is only of the 8.9th, instead of the 6th magnitude

96 Tauri is of the 8th, rather than of the 6th, magnitude.

62 Aries is of the 5th, and not of the 6th, magnitude.

12 and 14 Lynx are just the reverse of what Flamstead has made them, the one having changed from the 5th to the 7th, and the other from the 7th to the 5th, magnitude

38 Perseus, instead of the 6th, is equal to θ and κ of the 4th, magnitude.

θ Perseus is less than τ.

δ Unicorn is less than 76 Orion, though the former should be of the 4th, and the latter of the 6th, magnitude

23 Gemini, though of the 5th, is less than the 21st of the 6.7 magnitude.

26 Orion is either lost, or has diminished greatly in magnitude

ζ Lion is less than the 5th, though Flamstead makes it of the 4th, magnitude.

Stars that have recently become visible.

The following stars are marked by Dr. Herschel as among the stars that have recently become visible.

A star in the end of the Lizard's Tail, of the 4.5 magnitude, is not recorded by Flamstead, though he notices the 1st of the Lizard.

The star of the 8th magnitude, following τ Perseus, is probably new.

A star near the Head of Cepheus is not given by Flamstead.

A considerable star, in a direction from the 68th to the 61st Gemini, is not in Flamstead's catalogue.

A star of considerable brightness, preceding the 1st of the Little Horse, is not given by Flamstead.

A considerable star, following the 1st of the Sextant, and another following the 7th, are not in Flamstead's catalogue.

A remarkable star between β and ι Hydra, is not given by Flamstead.

A star nearly 1° 30′ north following δ Hercules, in the direction of δ and ν, and of the 4.5 magnitude, is not given by Flamstead.

About 3° south preceding γ Bootes, is a star of the 6th magnitude; and south preceding λ, is another of the same size, not observed by Flamstead.[3]

III. ON SINGLE, OR INSULATED STARS.[4]

By the name of insulated stars, Dr. Herschel denotes those celestial bodies which are in a great degree out of the reach of the attractive force of other stars, such as our Sun, Arcturus, Capella, Lyra, Sirius, Canopus, Markab Bellatrix, Menkar, Shedir, Algorah, Propus, and probably many others. It is obvious that no two stars in the universe can be altogether out of the sphere of each other's attraction; but in the case of Sirius and our Sun, which, upon the supposition that their masses are equal, and that the former has a parallax of 1″, would take 33 millions of years to fall to one another by their mutual action, we are entitled to say that they are insulated. Insulated stars are considered by Dr. Herschel as the centres of extensive planetary systems like our own; an opinion which he deduces from analogy, and from the nature of other sidereal combinations. Instead of supposing, therefore, as has generally been done, that every star in the firmament is encircled with planets, satellites, and comets, Dr. Herschel believes that the insulated stars alone are surrounded with such numerous attendants.

IV. OF DOUBLE STARS, OR BINARY SIDEREAL SYSTEMS.

On double stars.

A binary sidereal system, or a double star properly so called, is formed by two stars situated so near

[3] See *Phil. Trans.* 1783, vol. lxxiii, p. 247, &c.

[4] In the remaining articles of this Chapter, we have followed the classification adopted by Dr. Herschel.

each other, as to be kept together by their mutual gravitation. The two bodies may revolve round their common centre of gravity in circles, or in similar ellipses, the dimensions of their orbits being proportional to their relative quantities of matter.

Two stars may have the appearance of a double star, though they do not form a binary system, when the one is situated at an immense distance behind the other, but a little on one side of the line in which we see the first. They are in this case out of the reach of one another's attraction, though in the heavens they appear to be contiguous.

Dr. Herschel has shewn, that no two insulated stars can appear double to us, and that there are very many chances against the supposition that the great number of double stars which he has discovered, should only appear to be double in consequence of the one being situated at a great distance behind the other, and out of the sphere of its attraction. Hence, he concludes, that as casual situations will not account for the numerous phenomena of double stars, their existence must be owing to their mutual gravitation.

This interesting conclusion, however, is not founded merely on probabilities. From a series of observations on double stars, Dr. Herschel has actually found that they have changed their situations with regard to each other;—that the one performs a revolution round the other, and that the motion of some of them is direct, while that of others is retrograde.

From the motion of our Sun in absolute space, it is natural to suppose that it performs a revolution round some distant centre; but Dr. Herschel believes that the Sun does not belong to any binary system, and that its progressive motion is owing to some perturbations arising from the proper motion of neighbouring stars and systems.

From a series of observations made during a period of 25 years, Dr. Herschel has found that in more than 50 of the double stars there is a change either in the distance of the two stars or in the angle that a line joining them forms with the direction of their daily motion, which he calls the *angle of position.* A few only of these interesting observations have been published. They relate to six double stars, viz. α Geminorum, γ Leonis, ε Bootes, ζ Herculis, δ Serpentis, and γ Virginis.

Castor.—*Castor*, or α *Geminorum*, was observed by Dr. Herschel from the year 1778 to the year 1803. He never could

perceive any variation in the distance of the two stars, which was uniformly 1 7/8 of the diameter of the large one. See Plate VI, *Sup.* Fig 2. In the angle of position, however, a remarkable change had taken place. In the year 1779, November 5th, it was 32° 17′ N. preceding,[5] and on March 27th 1803, it had diminished to 10° 53′, which was a decrease of 21° 54′, in the space of 23 years and 142 days. From the measures of this angle, taken at intermediate times, it appears that the angle of position has suffered an irregular and gradual diminution. In the year 1759 Dr. Bradley had observed that the line joining the two stars which form Castor was, at all times of the year, parallel to the line joining Castor and Pollux, and Dr. Maskelyne had verified this result in 1760 or 1761. By this observation, Dr. Herschel has obtained an addition of 20 years to the period, and has found that the angle of position must then have been 56° 32′ N. preceding. Hence, in the space of 43 years 142 days, the angle of position has diminished 45° 39′; and, from the regularity of its decrease, it is highly probable that the orbits in which the two stars move round their common centre of gravity are nearly circular, and at right angles to the line in which we see them; and that the time of a whole apparent revolution of the small star round Castor will be nearly 342 years and 2 months in a retrograde direction.

γ Leonis.—The distance of the two stars which compose the double star of γ Leonis, has undergone a decided change from February 16th 1782 to March 26th 1803. From an immense number of observations, it appears that the two stars were, in 1803, one half of a diameter of the small one farther asunder than they were in 1782, when the interval was ½ a diameter of the small star, with a power of 2010. The diameters of the two stars were as 5 to 4. The angle of position, on the 16th February 1782, was 7° 37′ north following, and on the 26th March 1803 it had diminished to 6° 21′ south following. From the interval between the two stars, the ratio of their diameters, and the variation in the angle of position, Dr. Herschel has found that the apparent orbit of the small star is elliptical, and

[5] North preceding signifies that the smaller star is north of the larger one, and precedes it in their diurnal motion; and north following denotes that the one is north of the other, and follows it in their diurnal motion. South preceding and south following indicate the same thing, with this difference only, that the small star is south of the other.

that it performs a whole revolution in about 1200 years, in a retrograde direction.

ε *Bootes.*—The beautiful double star of ε Bootes is composed of two stars, one of which is of a light red, and the other of a fine blue colour, having the appearance of a planet and its satellite. With a power of 460, and an aperture of 6.3 inches, the distance between the two stars in 1781 was $1\frac{1}{2}$, the diameter of the large star, and in 1803 the interval had increased to $1\frac{3}{4}$ of that diameter. The ratio of the size of the stars is as 3 to 2. On the 31st of August 1780, the angle of position was 32° 19′ north preceding, and on the 16th March 1803, it had increased to 44° 52′, which is a change of 12° 33′ in the space of 22 years and 207 days. From these facts, Dr. Herschel concludes that the orbit of the small star is elliptical, and performs its revolution, according to the order of the signs, in 1681 years.

ζ *Herculis.*—The double star ζ Hercules is composed of a greater and a lesser star, the former of which is of a beautiful bluish white, and the latter of a fine ash colour. On the 18th of July 1782, the interval between the two stars was one half the diameter of the smaller one, with a power of 460. On the 21st July of the same year their distance remained the same, but with a power of 987; they were one full diameter of the small star asunder. In 1795, Dr. Herschel found it difficult to perceive the small star. In the month of October 1795, however, he saw it distinctly, with a power of 460. In 1802, he could no longer perceive the small star; but in a clear night in September of that year, with a power of 460, the apparent disc of ζ Hercules seemed to be a little lengthened in one direction. With the ten feet telescope, and a power of 600, it had the appearance of a lengthened or rather wedge-formed star. With a power of 2140, he again examined it on the 11th of April 1803, and found the disc a little distorted; but he was convinced that not more than three-eighths of the apparent diameter of the small star was wanting to a complete occultation. The angle of position, on the 21st July 1782, was 20° 42′ north following.

δ *Serpentis.*—The double star of δ Serpentis has, like ε Bootes, undergone a considerable change in the angle of position, without any variation in the distance between the two stars. On the 5th of September 1782 the angle of position was 42° 48′

south preceding; and on the 7th February 1802 it was 61° 27′ south preceding, having sustained a diminution of 18° 39′ in the space of 19 years and 155 days. Hence the period of a complete revolution of the smaller star will be about 375 years.

γ Virginis.—The double star of γ Virginis, which has long been known to astronomers, is composed of two stars, which Dr. Herschel at first considered as nearly equal, though he has since ascertained that the one is a little larger than the other. Their distance, which is about 2½ diameters, has continued the same for 21 years, while the angle of position has varied considerably. On the 21st November 1781, the angle of position was 40° 44′ south following, or rather north preceding, since the other star was afterwards found to be the smaller of the two; and on the 15th of April 1803, the angle of position was 30° 20′ north preceding, having suffered a diminution of 10° 24′ in 21 years and 145 days. From an observation of Mayer's, however, in 1756, Dr. Herschel has found the angle of position for that year to be 54° 21′ 37″ north preceding, which gives a motion of 24° 2′ in 47 years and 105 days. Hence he concludes that a complete revolution is performed in about 708 years.

M. Bessel of Konigsberg, who has recently attended to the motion of double stars, has concluded "that the double stars form a particular system by themselves. Several stars of this kind, by their common motion, shew a mutual dependence; but the one most worthy of being remarked is the star in the Swan (See Dr. Herschel's 4th class, in the following Table), which is the 61st in the catalogue of Flamstead. This double star has a great velocity. It is evident that the two stars are held together by their mutual attraction; and that during 60 years they have described a considerable part of their orbit round their common centre of gravity." In confirmation of these views, M. Bessel (*Journal of Gotha*, August 1812, p. 141, September 1812, p. 295) adduces the observations of Hevelius, Flamstead, Bradley, Herschel, Agelet, Lalande, and Piazzi. The longitude of the star for 1800 he makes 314° 29′ 5″.88, and its latitude 37° 46′ 30″ 27 N. The proper annual motion in longitude being 5″.0683, and in latitude 3″.3580. He supposes its time of revolution to be about 400 years; the half of its greater axis 25″9; and the annual parallax 0″.46. In these results neither the observations of Hevelius nor Piazzi are included,

because the former are too uncertain, and the latter too modern. By including Piazzi's observations, he obtains for the two stars—

	Longitude.	N. Latitude.
1805,	314° 32′ 28″.5	37° 47′ 54″.6
	314 32 46 5	37 47 57 5
Proper motion,	+ 5″.1750	+ 3″.2657

See De Lambre's *Astronomie*, vol. iii, p. 198.

Remarks on the Catalogue of Double Stars.

Having thus given an account of some of the principal revolutions of double stars, we shall now lay before our readers a complete catalogue of double stars, containing the angle of position, the distance of the stars, their colour, and their relative magnitudes, according to the observations of Dr. Herschel.

Dr. Herschel has divided double stars into six classes. In the *first* class he has placed all those that require a very superior telescope, and the most favourable circumstances, to be distinctly seen. In order to perceive the most minute of these delicate objects, such as η of the North Crown, Dr. Herschel advises that the telescope should be first directed to α Gemini, or to ζ Aquarius, μ Dragon, ρ Hercules, α Pisces, or ε Lyra, that the eye may be accustomed to this class of objects. The telescope should next be turned to ξ in the Great Bear, to the treble star in the Unicorn's right fore-foot, to *i* Bootes, which is a fine miniature of α Gemini, to the star preceding α Orion, to *n* Orion, and then to η in the North Crown. All these Dr. Herschel has observed with a power of 227. When the stars are of unequal magnitudes, he recommends them to be examined in the following order: α Hercules, ω Auriga, δ Gemini, *k* Swan, ε Perseus, *b* Dragon, and then the beautiful star ε Bootes. The *second* class of double stars contains those in which the two stars are so near each other, that their distance may be estimated by the eye, in diameters of either of the stars. The *third* class contains all those in which the two stars are more than 5″ but less than 15″, asunder. The stars in this class may be seen by telescopes that magnify from 40 to 100 times, and should be observed in the following order: ζ Great Bear, γ Dolphin, π Bootes, γ Virgin, ι Cassiopeiæ, and μ Swan.

The *fourth* class contains those stars whose distance is from 15″ to 30″. The *fifth* class contains those whose distance is from 30″ to 1′; and the *sixth* class those whose distance is from 1′ to 2′, or more.

In order to perceive the closest of the double stars, Dr. Herschel advises that the power of the telescope should be adjusted upon a star known to be single, of nearly the same altitude, magnitude, and colour, with the double star which is to be observed, or upon one star above and another below it. Thus Mr. Aubert could not see the two stars of γ Leonis, when the focus was adjusted upon that star itself; but he soon observed the small star, after he had adjusted the focus upon Regulus.

In the following Table, N P ; S P ; N F ; S F ; stand for North Preceding, South Preceding, North Following, South Following. L stands for the larger of the two stars, and S for smaller. In column 5th, *V.* signifies very unequal ; *S.* slightly unequal ; *E.* extremely unequal ; *Ex.* excessively unequal ; *C.* considerably unequal ; *P.* pretty unequal ; *Eq.* equal.

The following Table contains an account only of the principal stars in Dr. Herschel's catalogue, as the limits of this work would not permit us to give the whole of them. In the next Table, however, we have in some measure supplied this defect, by giving the positions of all those that have been omitted in Table I ; so that, with a little trouble, the practical astronomer may find them in the heavens.

TABLE I.—Containing a Description of the principal Double Stars in Dr. HERSCHEL'S Catalogue.

FIRST CLASS.

No. in Flamsteed's Catal.	Names of the Constellations in which they are placed.	Letters according to Bayer.	Angle of Position formed by the line joining the Stars and the parallel of Declination.	Distance between the Stars, and relative Magnitude.	Colour of the Stars, L. denoting the larger and S. the smaller of the two.
36	Bootes	ε	31° 54′ N.P.	$1\frac{1}{2}$ dia.L. *V.*	L. reddish, S. blue.
53	Great Bear	ξ	53 47 S.F.	$\frac{2}{3}$ *S.*	Both white and bright.
8	Cassiopeia	σ	66 28 N.P.	1 *V.*	L. reddish wh. S. dusky.
39	Dragon	*b*	77 8 N.F.	$\frac{3}{4}$ *E.*	L. white, S. reddish.
63	Dragon	ε	63 14 N.P.	1 *E.*	L. white, S. dusky.
59	Serpent	*d*	11 33 N.P.	1 *V.*	L. reddish white, S. blue.
44	Bootes	*i*	29 54 N.F.	$\frac{1}{1}$ S. *C.*	Both white.
2	Northern Crown	η	59 19 N.F.	$\frac{1}{1}$ *S.*	Both whitish.
33	Orion	*n*	60 55 N.F. Two nearest	$\frac{1}{2}$ S. *C.*	L. white, S. bluish white.
32	Orion	A	52 10 S.P.	$\frac{1}{4}$ *C.*	L. white, S. rosy white.
2	Lion	ω	20 54 S.F.	In cont. *C.*	Both red.
41	Lion	γ	5 24 N.F.	$\frac{1}{6}$ S. *P.*	L. white, S. reddish white.
40	Hercules	ζ	20 42 N.F.	$\frac{1}{2}$ *V.*	L. white, S. ash colour.
11	Hercules star N. & Fol	φ	59 48 S.F.	1 *C.*	Both reddish.
13	Serpent	δ	42 48 S.P.	$\frac{1}{3}$ S. *C.*	L. white, S. greyish.
81	Virgo		41 12 N.F.	$\frac{1}{2}$ *Eq.*	
49	Serpent		21 33 N.P.	$\frac{1}{3}$ *S.*	
10	Ophiuchus	λ	14 30 N.F.	$\frac{1}{3}$ S. *C.*	L. white, S. blue.
52	Eagle	π	34 24 S.F.	$\frac{1}{2}$ *S.*	
18	Swan	δ	18 21 N.F.	$\frac{1}{2}$ *V.*	L. white, S. reddish.

SECOND CLASS.

66	Gemini, *Castor,*	α	32° 47′ N.P.	1 S. or 5″ *S.*	Both white.
64	Hercules	α	30 35 S.F.	$1\frac{3}{4}$ or 4″.6 *V.*	L. red, S. bluish green.
75	Hercules	ρ	30 21 N.P.	$1\frac{1}{1}$ or 3 *P.*	Both white.
70	Serpentarius	*p*	9 14 S.F.	$1\frac{2}{3}$ *C.*	L. white, S. reddish.
55	Aquarius	ζ	71 39 N.F.	$1\frac{1}{4}$ or 4 .6 *Eq.*	Both white.
7	Northern Crown	ζ	25 51 N.P.	3 or 5 .5 *C.*	L. white, S. reddish white.

39	Orion	λ	45° 14′ N.F. 29 4 N.F.	1½ or 5″.8 *C.*	L. white, S. pale rose.
Last	Pisces	α	67 23 N.P.	2 or 5.1 *C.*	Both white.
21	Dragon	μ	37 38 S.P.	1½ or 4.4 *Eq.*	Both white.
4	Auriga	ω	82 37 N.P.	2 *V.*	L. white, S. red.
24	Swan	ψ	89 32 N.P.	1¼ *E.*	L. white, S. red.
17	Cepheus	ξ	20 18 N.P.	2 or 5 *C.*	L. reddish white, S. dusky grey.
37	Bootes	ξ	65 53 N.F.	1½ or 3.4 *V.*	L. red, S. deeper red.
5	Serpentarius	*g*	82 10 S.P.	1½ *P.*	Both white.
Last	Libra	ξ	1 set 1 23 N.F.	2 or 6.4 *V.*	L. fine white.
45	Perseus	ι	81 28 S.F.	2½ *E.*	L. white, S. dusky.
52	Swan	*k*	28 17 N.F.	2¼ *E.*	L. reddish white, S. dusky and faint.
55	Gemini	δ	85 51 S.P.	2½ *E.*	L. reddish white, S. redd.
8	Arrow	ζ	34 10 N.P.	4½ or 5.5 *E.*	
19	Orion	β	68 12 S.P.	6.5 *E.*	L. white, S. reddish.
6	Triangle	ι	4 23 N.F.	1¼ *V.*	L. pale red, S. bluish red.
23	Cancer	2 φ	56 42 N.F.	2 *S.*	Both reddish white.
24	Cancer	1 υ	32 9 N.F.	1½ *C.*	Both pale red.
84	Virgo	●	29 5 S.P.	2½ *E.*	L. reddish white, S. dusky
2	Berenice's Hair		27 42 S.P.	*C.*	L. reddish wh. S. pale red.
38	Pisces		25 3 S.P.	2 *P.*	Both pale red.
11	Capricornus		84 0 S.F.	1½ *V.*	Both reddish white.
18	Lynx, the most southern, 1¼° S. towards θ Gemini.	ε	11 0 S.P.	2½ nearly *Eq.*	Both pale red.
118	Taurus		77 15	2½ or 5 *S.*	L. white, S. reddish white.
17	Hydra, the largest of two		90 0 north	2¼ *S.*	Both white.
39	Bootes		38 20 N.F.	1½ *S.*	Both pale red.
65	Pisces		30 57 N.P.	1½ nearly *Eq.*	Both pale red.
49	Swan		31 48 N.F.	1½ *V.*	L. red, S. bluish red.

THIRD CLASS.

59	Great Bear	ζ	56° 46′ S. F.	14″.5	*C.*	L. white, S. rosy white.
28	Cassiopeia	η	27 56 N.F.	11 .3	*V.*	L. fine white, S. fine garnet.
55	Cassiopeia		10 37 S. F.	7 .5	*E.*	L. white, S. bluish red.
67	Andromeda	γ	17 37 N.F.	9 .3	*V.*	L. reddish white, S. greenish blue.
8	Cepheus	β	15 28 S. P.	13 .1	*V.*	L. bluish white, S. garnet.
8	Scorpio	β	64 51 N. F.	14 .4	*V.*	L. whitish red, S. red.
29	Bootes	π	6 28 S. F.	6 .2	*P.*	L. white, S. reddish white.
5	Aries	γ	86 5 N. P.	10 .2	*Eq.*	
12	Dolphin	γ	4 9 N. P.	11 .8	*Eq.*	Both white.
17	Bootes	κ	30 0 S. P.	12 .5	*V.*	L. white, S. dusky.
78	Swan	μ	20 15 S. F.	6 .9	*C.*	L. white, S. bluish.
1	Dolphin		9 42 S. P.	12 .5	*S.*	Both white.
1	Lizard's Tail		76 16 S. P.	13 .7	*C.*	L. white, S. dusky red.
29	Virgo	γ	40 44 S. F.	7 .3	*Eq.*	Both white.
16	Cancer	ζ	88 16 S. P.	8 .0	*C.*	Both pale red.
39	Serpentarius		87 14 N.P.	10 .0	*V.*	L. white, S. bluish.
95	Hercules		4 9 S. P.	6 .1	*Eq.*	Preceding white, following bluish white.
54	Leo		9 14 S. F.	7 .1	*C.*	L. bright white, S. greyish white.
43	Hercules	ι	88 23 N.F.	11 .7	*Eq.*	Preceding reddish white, following white.
38	Gemini	ε	89 54 S. F.	7 .8	*E.*	L. reddish white, S. red.
88	Leo		Two nearest 47 33 N.P.	14 .6	*E.*	L. reddish white, S. red.
13	Perseus	θ	20 0 N.P.	13 .5	*E.*	L. reddish white, S. dusky.
35	Pisces		58 54 S. F.	12 .5	*C.*	L. reddish wh. S. pale red.
26	Auriga		2 36 N.P.	13 .4	*V.*	L. reddish white, S. red.
	Taurus	ε	17 15 N.F.	11 .3	*E.*	L. white, S. red.
1	Cepheus	κ	32 30 S. F.	5 .8	*E.*	L. fine white, S. red.
41	Auriga		80 0 N.P.	8 .5	*C.*	L. white, S. reddish grey.
19	Lynx		46 54 S. P.	14 .2	*S.*	L. reddish white, S. bluish white.
40	Lynx		48 12 N.P.	7 .2	*V.*	L. whitish red, S. red.
2	Canes Venatici		11 0 S. P.	12 .2	*V.*	L. red, S. bluish.
57	Great Bear		75 36 N.F.	Just vis.	*Eq.*	L. white, S. a red point.

117	Taurus		52° 27′ S. F.	12″.2	*Eq.*	Both reddish white.
17	Cup		64 27 S. P.	9 .8	*Eq.*	Both reddish white.
54	Hydra		38 15 S. F.	11 .3	*V.*	L. white, S. bluish red.
55	Eridanus		14 9 N.P.	9 .1	*S.*	L. pale red, S. reddish wh.
3	Centaurus	λ	22 0 S. F.	11 .6	*C.*	L. dusky, S. dusky p red.
5	Serpent		30° or 40° N. F.		*Ex.*	L. reddish white, S. dusky blue.

FOURTH CLASS.

1	Little Bear Pole Star	α	66° 42′ S. P.	17″.2	*E.*	L. white, S. red.
20	Lyra	η	31 51 S. P.	25 .7	*C.*	L. white, S. red.
	Capricornus	ζ		25 .0	*E.*	
	Perseus	η	25 0 N.P.	26 .0	*V*	L. red, S. blue.
33	Aries		87 14	25 .5	*C.*	L. white, S. dusky.
63	Serpent	θ		19 .4	*Eq.*	Both white.
31	Dragon	ψ		28 .2	*P.*	L. white, S. pale red.
86	Pisces	ζ	22 37 N.F.	22 .2	*P.*	L. white, S. bluish white.
74	Pisces	1 ψ	80 0 S. F.	22 .5		
59	Taurus	χ'		18 .7		
17	Swan	χ		24 .9	*V.*	L. white, S. dusky red.
91	Aquarius	ψ		23 .1	*Uneq.*	
83	Leo		54 55 S. F.	29 .1	*S.*	Both reddish.
12	Cor Caroli		41 47 S. P.	20 .0	*V.*	L. white, S. reddish.
61	Swan		36 28 N.F.	16 .1	*P.*	L. red, S. garnet.
14	Auriga		37 38 S. P.	16 .1	*V.*	L. reddish wh. S. dusky.
47	Dragon	ο	90 0 N.	26 .6	*V.*	L. pale red, S. dusky red.
60	Orion	ζ	83 25 N.F.	25 .0	*V.*	L. white, S. dusky.
63	Swan	*f*		18 .2	*E.*	L. fine white, S. dusky.
45	Swan	2 ω	7 23 N.P. two brightest.	30 .0	*C.*	L. reddish wh. S. dusky.
24	Berenice's Hair		3 28 N.P.	18 .4	*C.*	L. whitish red, S. bluish red.
23	Great Bear	*h*	3 14 N.P.	19 .2	*E.*	L. reddish wh. S. dusky.
61	Serpentarius, near γ		Directly following.	19 .1	*S.*	L. white, S. grey.
6	Dolphin	β	78 0 N.P.	25 .9	*E.*	
28	Serpent	β	3° or 4° S.P.	24 .0	*E.*	L. white, S. faint.
7	Little Horse	δ	11 39 N.F.	19 .5	*Ex.*	
24	Aquarius			25 .0	*V.*	L. white, S. dusky.
10	Triangle	α		17 .3	*Uneq.*	
86	Hercules	μ	30 0 S. P.	18 .0	*Ex.*	L. palish red, S. dusky.
17	Virgo		58 21 N.P.	20 .1	*C.*	L. white, S. bluish.

44	Virgo	k	32°	30′	N.F.	22″.3	F.	L. white, S. dusky blue.
48	Cancer	ι	39	54	N.P.	29 .9	C.	L. reddish white, S. dusky garnet
80	Gemini	π				21 .5	Fr	L. garnet, S. dusky.
18	Libra		44	45	N.F.	18 .0	E.	L. red, S. blue.
42	Hercules		3	42	S.F.	21 .5	F.	L. red, S. reddish white
40 and 41	Dragon		65	15	S.P.	20 .6	S.	L. reddish white, S. pale red.
77	Pisces		4	48	N.F.	29 .6	S.	L. whitish red, S. pale red
51	Pisces		0	36	N.F.	22 .5	F.	L. reddish white, S. duskish.
12	Capricorn	o	30	45	S.P.	23 .6	P.	Both reddish white.
13	Cepheus	μ	77	48	S.P.	21 .1	S.	L. white, S. reddish white
6	Great Dog Star	ν	Very near directly prec.			18 .3	C.	L. reddish white, S. pale red.
26	Whale		14	36	F.P.	17 .0	F.?	L. reddish white, S. dark blue.
23	Orion	m	59	33	N.F.	26 .1	C.	L. white, S. pale red.
	Taurus		23	15	N.F.	19 .8	F.	L. pale red, S. dusky red
27	Ship		69	12	N.P.	17 .4	S.	L. white, S. reddish white
	Unicorn		15	12		29 .9	F.	L. whitish red, S. dusky.
59	Auriga		50	3	S.P.	23 .5	E.	L. reddish white.
7	Crow	δ	54	0	S.P.	23 .5	F.	L. white, S. red.
62	Taurus		21	12	N.P.	28 .1	C.	L. white, S. red.
54	Cancer		29	0	S.F.	17 .2	S.	Both reddish white.
19	Ophiuchus		3	9	S.F.	20 .4	V.	L. pale red, S. dusky.
29	Camelopard		47	36	S.F.	22 .4	V.	L. pale red, S. dusky.
59	Andromeda		55	9	N.F.	15 .2	S.	L. reddish wh. S. pale red.
100	Pisces		5	0	N.F.	15 .9	P.	L. pale red, S. red.

FIFTH CLASS.

11	Hercules	δ	72°	28′	S.F.	33″.7	E.	L. white, S. reddish wh.
6	Lyra	ζ	62	18	S.F.	42 .0	P.	L. white, S. rosy white.
27	Cepheus	δ	36	28	N.F.	38 .3	C.	L. reddish white, S. bluish white.
6	Swan	β	69	28	N.P.	39 .5	C.	L. pale red, S. fine blue.
14	Scorpio	ν	79	37	N.F.	38 .3	V.	Both white.
7	Hercules	κ	52	51	N.F.	40 .0	S.	L. pale red, S. red
21	Bootes	ι	88	10	N.P.	37 .6	V.	L. white, S. dusky.
34	Orion	δ	88	10	N.P.	53	C.	L. white, S. bluish red.
24 25	Dragon	ν	44	19	N.P.	54 .5	S.	Both pale red.

9	Aries	λ	42°	0′	N.F.	36″,7	C.	L. pale red, S. dusky garnet.
16	Great Bear	c	80	47	S.P.	49	V.	L. whitish red, S. dusky.
76	Pisces	σ	15	28	N.P.	43 .1	E.	L. pale red, S. dusky red.
18	Cassiopeia	ω	40	58	N.P.	52 .8	E.	L. pale red, S. dusky.
20	Hercules	γ	19	50	S.P.	11 .8	E.	L. reddish white, S. red.
1	Pegasus	c	28	19	N.P.	37 .1	V.	L. pale red, S. dusky.
6	Lion	h	12	55	N.F.	35 .8	V.	L. red, S. dusky.
	Andromeda	α	10	37	S.P.	55 .5	E.	L. white, S. dusky.
3	Lyra	α	26	46	S.F.	37 .2	E.	L. bright white, S. dusky.
15	Gemini		60	0	S.P.	32 .6	V.	L. red, S. dusky.
7	Lion		8	36	N.F.	42 .4	V.	L. reddish white, S. red.
31	Cancer	θ			N.F.	44 .9	E.	L. red, S. dusky.
36 and 37	Hercules	m	33	57	S.P.	60	S.	L. bluish white, S. reddish white.
14	Great Bear	τ	45	0	N.F.	54 .8	E.	L. white, S. dusky.
22	Aquarius	β	55	48		33 .3	Ex	L. white, S. dusky.
38	Sagittarius	ζ	28	6	N.P.		E.	L. red, S. dusky.
69	Aquarius	τ	19	54	S.F.	36 .8	V.	L. reddish wh. S. dusky.
36	Cassiopea	ψ	10	12	S.F.	33 .4	V.	L. pale red, S. red.
7	Capricorn	σ	35	12	S.F.	50 .1	V.	L. red, S. dusky blue.
32	Auriga	ν	51	48	S.P.	53 .7	Ex	L. orange white, S. red.
10	Lizard		38	45	N.F.	52 .5	V.	L. white, S. red.
3	Pegasus		82	48	N.P.	34 .7	P.	L. whitish red, S. dusky red.
33	Pegasus		89	12	N.F.	45 .1	C.	L. pale red, S. red.
61	Whale		76	21	S.P.	37 .9	E.	L. reddish white, S. dusky red.
56	Auriga		72	36	N.F.	53	C.	L. white, S. pale red.
	Between β Cancer & δ Hydra.		55	0	N.P.	35 .4	Ex.	
111	Taurus		3	48	N.P.	46 .7	V.	L. reddish white, S. red.
103	Taurus		72	24		30	Ex.	L. reddish white, S. dusky.
114	Taurus	'o	77	54	S.P.	50	Ex.	L. white, S. a point.
12	Berenice's Hair	e	77	0	S.F.	58 .9	C.	L. reddish white, S. pale red.
	Andromeda's Breast		32	24	S.P.	45	Eq.	S. pale red.
35	Berenice's Hair		86	51	S.F.	31 .3	V.	L. red, S. dusky.
60	Hercules		37	0	N.P.	48 .7	E.	L. white, S. dusky.

Sixth Class.

68	Whale	o		1' 49"	*V.*	L. garnet, S. dusky.
11	Lyra	δ	S. P.	4	*E.*	S. dusky.
5	Capricorn	α		1 15	*V.*	L. red, S. dusky.
43	Gemini	ζ	81° 14' N.P.	1 31 .9	*V.*	L. reddish wh. S. dusky red
32	Lion	α	30 5 N.P.	2 48 .3	*V.*	L. white, S. dusky.
84	Lion	τ	73 29 S. F.	1 22 .7	*C.*	L. red, S. bluish.
95	Lion	δ	80 0 N.F.	1 30	*E.*	L. reddish wh. S. dusky.
58	Serpent	η	9 7 S. F.	1 21	*E.*	L. pale red, S. dusky.
49	Bootes	δ	5 46 N.F.	2 15	*C.*	L. reddish wh. S. white.
51	Bootes	μ	80 25 S. F.	2 8	*Uneq.*	L. reddish wh. S. pale red.
11	Arrow		8 32 S. F.	1 31 .9	*V.*	L. red, S. bluish red.
9	Capricorn	β	Preceding	3 0	*C.*	
13	Auriga	α	33 42 S. F.	2 49 .1	*E.*	L. white, S. dusky.
54	Swan		12 42 S. F.	1	*E.*	L. bluish white, S. dusky.
58	Orion	α	62 18 S. F.	2 6	*E.*	L. red, S. dusky.
51	Virgo	θ	24 55 N.P.	1 3 .9	*E.*	L. white, S. dusky.
24	Libra	ι	22 31 S. F.	1 5 .2	*V.*	L. white, S. dusky red.
87	Taurus, *Aldebaran*	α	52 58 N.F.	1 27 .7	*E.*	L. red, S. dusky.
28	Orion	η	35 12 N.F.	1 51	*Ex.*	L. white, S. dusky.
14	Aries		11 12 N.P.	1 29 .5	*Ex.*	L. pale red, S. dusky red.
14	Lion	o	49 36 N.F.	1 3 .5	*E.*	L. reddish white, S. red.
74	Lion	φ	10 or 12 N.P.	1 38 .6	*V.*	L. white, S. pale red.
34	Auriga	β	54 12 N.F.	2 49 .1	*Ex.*	L. bluish white, S. dusky.
61	Virgo		75 0 N.P.	1 13 .2	*V.*	L. white, S. dusky.
15	North Crown	ρ	54 27 S. F.	1 27 .7	*V.*	L. white, S. dusky.
12	North Crown	λ	33 12 N.F.	1 35 .2	*E.*	L. white, S. red.
8	Bootes	η	25 or 30 S. F.	1 30	*E.*	L. orange white, S. red.
57	Perseus	*m*	71 51 S. P.	1 36 .4	*P.*	L. red, S. reddish.
5	Lynx		2 0 N.P.	1 28 .3	*V.*	L. red, S. garnet.
8	Pegasus	ε	52 45 N.P.	1 30 .9	*V.*	L. pale red, S. dusky red.
105	Taurus		18 0 S. P.	1 41 .5	*V.*	L. pale red, S. red.
106	Eridanus	*b*	15 9 N.F.	1 0 .4	*C.*	L. white, S. pale red.
13	Bootes		7 24 N.P.	1 17 .9	*E.*	L. red, S. dusky red.
4	Virgo			2 25 .7	*E.*	L. whitish red, S. dusky red.
43	Hercules		38 48 S. P.	1 14 .6	*V.*	L. inclining to garnet, S. red.
30	Unicorn			3 30 .9	*V.*	
12	Lizard		73 0 N.F.	1 0 .1	*V.*	L. white, S. red.
58	Eagle	α	64 44 N.P.	2 28 .18	*E.*	L. white, S. dusky.

TABLE II. Containing the Names of the Double Stars observed by Dr. Herschel, but not contained in the preceding Table.

FIRST CLASS.

16 Dragon.
38 Middle of Lynx's Tail.
11 Cancer.
24 Eagle.
Near 51 Bootes.
Smallest of the two between θ and δ N. Crown.
h Dragon.
52 Orion.
c Triangle.
In the hind thigh of the Little Dog.
Near 44 Lion.
2 ι Cancer.
Between 39 and 41 Lynx.
South preceding 44 Lynx.
55 Cassiopeia.
38 Serpentarius.
N. preceding 18 Perseus.
S. preceding β Cassiopeia.
N. preceding 25 Cassiop.
North of 31 Dragon.
Near 4 σ Dragon.
4 Aquarius.

S. preceding μ Auriga.
N. preceding 29 Capricorn.
Preceding 6 Cepheus.
N. preceding λ Cepheus.
Preceding λ Aquarius.
Following ι Cepheus.
N. following 25 Orion.
Preceding 30 Orion.
Preceding τ Orion.
N. preceding 8 Taurus.
S. following 54 Whale.
Following δ Lyre.
Between 1 and β Lyre.
S. following λ Lyre.
N. prec. 1 Little Horse.
S. foll. 2 Little Horse.
South of γ Little Horse.
N. following β Arrow.
S. preceding 23 Dragon.
Near the nebula in Auriga's foot.
Near 10 Orion.
In the Lynx's breast.

N. preceding ζ Bull.
S. P. 44 Great Bear.
65 Great Bear.
N. preceding β Aries.
N. preceding 39 Aries.
S. preceding 26 Orion.
In the Lynx's breast.
North of α in the Cup.
North of 11 Balance.
46 Hercules.
S. preceding π Serpent.
South of 50 Auriga.
S. following 36 Lynx.
North of 105 Hercules.
73 or q Ophiuchus.
69 or τ Ophiuchus.
N. preceding two stars at the 56 Andromeda.*
S. preceding β Aquarius.
N. preceding γ Eagle.
N. preceding 62 Eagle.
S. following 33 Swan.
Following 51 Swan.

SECOND CLASS.

11 In the Unicorn's left foot.
Near 11 Serpentarius.
108 Aquarius.
Near 42 Orion.
Near 54 Eagle.
Near 63 Eagle.
56 Dragon.
Near 6 Triangle, following ι.
32 Eridanus.
In a cluster of six stars in the Unicorn's head.
Largest of three S. following 15 Bootes.
2° S. following Procyon.
1° 15′ S. P. k Virginis.
40′ S. P. 43 Lyon.
54 Virginis.
Near 42 Berenice's Hair.
S. preceding 16 Auriga.
30′ N. o Pisces.
30′ preceding 40 Perseus.
15′ prec. 12

30′ S. preceding ι Bull.
1° S. following 4 Whale.
1° N. preceding β Aries.
2° 30′ following κ Aquarius.
45′ S. following 56 Whale.
2° S. F. ρ Aquarius.
20′ N. F. ξ Great Dog.
30′ S. F. π Orion.
North of two stars 3 Pegasus.
30′ S. F. g Gemini.
45′ N. F. Pollux.
15′ S. P. γ Dolphin.
N. preceding β Lyre.
30′ N. following 4 Swan.
1° 15′ S. F. ε Arrow.
1° 15′ south of 13 Lynx.
21 Great Bear.
1° S. preceding ε Aries.
20′ S. following χ Lion.
20″ S. F. d Eridanus.
1° following 49 Eridanus.
1° S. following 31 Bootes.

30′ N. of 22 Andromeda.
1° 30′ N. F. b Serpent.
30′ S. P. 49 Serpent.
South of 29 and 30 Unicorn.
30′ S. P. ω Serpent.
1° N. P. 12 Unicorn.
1° 45′ N. P. 100 Hercules.
In the buttock of the Camelopard.
15′ S. following ι towards λ Eagle.
1° 20′ N. P. ι Andromeda.
20′ south of η Eagle.
1° 45′ N. F. θ Eagle, towards ι Dolphin.
1° 30′ N. F. β towards ξ Swan.
2° N. F. 51 Swan.
2° N. P. 57 towards 42 Camelopard.
30′ S. P. e Orion.

Third Class.

1 Little Horse.
12 Lynx.
34 Cassiopeia.
3 Ship.
Near 9 Ship
8 Unicorn.
Over ι Hercules.
11 Eagle.
Near 7 and 8 Eagle.
94 Aquarius.
54 Serpentarius.
South of γ Perseus.
40 or 2 o Perseus.
Near 87 Hercules.
N. F. δ Triangle.
In the left fore-foot of the Unicorn.
In the Unicorn.
Near 10 Taurus.
In Bootes. Draw a line through π and ζ to the small star under the right foot, and erecting a perpendicular towards the left foot, of equal length, the end of it will point out this star.

Following the tip of the Unicorn's ear.
30′ N. P. τ Gemini.
1° 15′ N. P. δ Hydra.
45′ N. F. 10 Orion.
2° 30′ N. F. γ Virgin
13 or 2 σ Great Bear.
N. F. 18 or υ N. Crown.
45′ N of a cluster formed by the 4, 5, 7, 9 of the Goose.
Near 19 Perseus.
20 or 2 p Perseus.
Between α and ι Dragon, that which is nearest..
30′ S. F. 65 Sagittarius.
10′ south of 58 Perseus.
3 or ι Hare.
1° S P. η Aries.
1° 30′ N. F. 64 Aquarius.
Preceding the tiara of Cepheus.
45′ S. F. 25 Whale.
45′ S. P. 18 Pegasus.
In the Unicorn's cheek.
45′ N. F. δ Orion.

45′ S. F. 65 Aries.
10° 45′ S. P. 13 Bull.
40 N. of ι Whale.
1° 30′ preceding σ Whale.
Above 30′ from ζ towards ι Lyra.
30′ N. F. 11 Bull.
4° from δ towards ι Hercules.
3° N. of 103 Bull.
1° N. F. 62 Aries.
1° N. P ξ Cancer.
1° 20′ N. P. ν Hare.
20′ S. P. ν Eridanus.
In the Unicorn's Cheek.
2° 15′ S. P. 55 Eridanus
1° 15′ S. P. h Hercules.
2° S. F. ι Serpent.
20′ preced. 83 Hercules.
N preceding γ Arrow.
North of the cluster of stars in Sagittarius.
45′ N. P. 19 Eagle.
1° 20′ N. P. 19 Eagle.
1° S. F. δ Swan
1° 15′ N. P. 16 Unicorn.

Fourth Class.

In the right ear of the Camelopard.
31 Cassiopeia.
Near the variable star o Whale.
19 Ship.
Near γ, and towards ζ Bull.
44 Lynx in the Eye or Nose of the Little Lion.
Near a star preceding θ Eagle.
N. F. ν Swan.
Beside ν Hercules.
λ Eridanus.
S. F. ε Bull.
30′ following ψ towards η Orion.
21 Gemini.
3 Lion.
1° N. F. ξ Virgin.
30′ F. δ towards ζ Hydra.
3′ 30″ N. F. 41 Lynx.
3° S. F. 42 Berenice's Hair.
2° 30′ N. P. 36 Berenice's Hair.
2′ or 3′ S. P. α Lyra.
1° N. F. 4 Great Bear.

30′ S. P. ζ towards η North Crown.
2° 30′ S. F. π Hercules.
Within a few minutes of q Perseus.
Within 10′ of 3 Cassiopeia.
1° 45′ S. P. θ Cassiopeia.
1° 30′ preceding 23 Andromeda.
15′ north of 55 Perseus.
Between 2 and 8 Camelopard.
30′ N. F. δ Bull.
1° 15′ N. F. τ Bull.
1° S. P. 13 Whale.
15′ N. P. 37 Whale.
1° 15′ preced. η Cepheus.
1° 45′ N. of β Great Dog.
45′ Following 16 Cepheus.
1° Preceding ε Orion.
The vertex of an isosceles triangle, following τ Aries.
Near 18 Great Bear.
3° Following ι Lyra.
2° N. P. β Lyra.
1° 15′ N. F. 25 Unicorn.

30′ Preceding α Orion.
45′ N. P. φ Auriga.
45′ Following 77 Dragon.
1° N. F. 55 Andromeda.
1° 45′ N F. α Great Bear.
45′ S. P. 79 Pegasus.
2′ S. of 69 Great Bear.
1° 45′ N. F. β Bull, the second towards θ.
1° N. F. γ Cup.
1° 15′ N. P. 61 Swan.
1° 30′ S. of ι Virgin.
2° 30′ S. P. φ Hercules.
N. F. 83 Pegasus.
1° 15′ S. of 42 Eridanus.
30′ F. 48 Cancer.
1° S. P. 68 Virgin.
45′ N. F. 82 Pisces.
20 or τ Scorpion.
1° N. P. 32 Ophiuchus.
45′ S. P. ψ Ophiuchus.
30′ N. P. λ Cepheus.
N. F. λ or 16 Eagle.
1° 20′ S. P. γ Andromeda.
1° 30′ N. F. η or 99 Pisces.
30′ N. F. 46 Eagle.

Fifth Class.

φ or 52 Bull.	p or 63 Gemini.	20′ S. P. ι Lyra.
π or 29 Andromeda.	θ or 22 Hydra.	30′ S. P. ι Lyra.
~ or 29 Auriga	45′ S. P. 95 or o Lion.	20′ S. F. y Arrow.
Following f Orion.	81 Lion.	1° 45′ N. P. γ Arrow.
Between η and θ Whale	57 Lion.	45′ N. κ Great Dog.
τ or 20 Orion.	25 Lion.	1° S. F. 42 Great Bear.
31 Libra.	1° South of 43 Lion.	Star forming isosceles triangle with μ and ν Gemini
Near β Cepheus.	45′ N P. p or 63 Gemini	1° 45′ N. P. ζ Aries.
ν or 53 Serpent.	1° N. F. Pollux.	The most northern of three preceding ι Orion.
53 Serpentarius, between α and β.	7 Little Lion.	45′ S. P. ι Orion.
Next but one preceding δ Eagle.	3 N. P. 2 Bootes.	15 Hydra.
h or 15 Eagle.	3′ or 4′ N. P. γ Gemini.	40′ S. P. 44 Bootes
Near 28 Eagle.	N. of S. or 72 Serpentarius.	1° 30′ S. F g Centaur.
Near that which follows θ Eagle.	1° S F. ι North Crown.	2° N. F. 46 Bootes.
o or 2 in the Shield in the Const. Eagle.	A few minutes N. F. d or 43 Sagittarius	30′ S. P. τ Hercules.
23 Hercules, between ν and ξ of the Crown.	9 Cassiopeia.	45° N. P. 41 Hercules.
43 or A Perseus.	35 Cassiopeia.	1° 30′ following ι Virgin.
Beside η Lyra.	15′ N. P. ν Cassiopeia.	1° 30′ N. F. f Virgin
76 Swan	47 Cassiopeia.	1° 30′ N. F. 24 Libra
S. F. τ Swan.	20′ N. P. ϱ Andromeda.	Between 29 and 30 Libra, but nearest 30.
c or 16 Swan, next foll. θ	3′ or 4′ N. F. γ or 15 Auriga.	1° S. P. ψ Ophiuchus.
ε or 26 Swan.	θ or 37 Auriga.	The smallest and most southern of two, about 20′ asunder, near 49 Camelopard
A little N of θ Pisces.	30′ S. F. β or 34 Auriga.	10 north of θ Eagle
30 over the Back of Aries	30′ S F. 3 Aries.	1° 20′ north of χ, towards δ Swan.
γ or 13 Hare.	1° 15′ S F. 103 Hercules.	
N. F. ι Arrow.	45′ N 31 Cepheus.	
Second star from ν towards μ Gemini.	51 Aquarius.	
	30′ S F. υ or 59 Aquarius.	
	59 Orion.	
	40′ Preceding υ Orion.	

Sixth Class.

o or 67 Serpentarius	32 Swan.	More S. than o Serpentar.
41 Aries, in the body of the Fly.	θ or 37 Auriga.	2 Cassiopeia, near e.
ι or 39 Capricorn.	13 Camelopard, over the Goat's Head.	θ Lyra.
τ or 94 Bull.	10 Camelopard.	79 Swan.
κ or 59 Bull.	c or 46 Dragon.	5 Aquarius.
o or 31 Swan.	e 64 or 65 Dragon.	28 Swan, near b.
Near 6 Bootes.	γ or 13 Hare.	Near 2 c Swan.
ν or 21 Crown.	67 or 5 ρ Cancer.	κ or 8 Pisces.
μ or 51 Perseus.	Near ι, and towards o Andromeda.	Near star N F. ι Arrow.
η or 44 Pegasus.	35 Eagle.	Near ν Eridanus.
Star between Dragon and the Tail of Great Bear.	Near 35 Eagle.	30′ S. F. η Orion.
In the Nostril of the Lynx.	The following star of a trapezium, near l Eagle.	τ or 31 Hydra.
3 Cassiopeia.	Star near the middle of Mount Menalus.	Near 68 Orion.
North of θ Eagle.	Between ι and f Bootes.	ι or 27 Gemini.
π or 10 Capricorn.	Star more S. than ι Bootes.	51 Gemini.
d or 88 Bull.		ω or 4 Cancer.
		τ or 93 Virgin.
		30′ following ζ Cancer.
		93 Lion.

27 Virgin.	20′ N. of ξ Capricorn.	22 or 26 Cancer.
31 Unicorn.	2 σ or 71 Aquarius.	Near ο Whale.
A few min. S. F. 1 Orion.	1° 30′ S. F. 46 B ll.	30′ S. P. 69 Orion.
27 Hydra.	1° 45′ N. F ι Cephеus.	2° 30′ S. F. 21 Cup.
1 ι or 51 Cancer.	ζ or 30 Bootes.	1° 15′ N. P. 12 Libra.
Following 6 Bootes.	1° 15′ S. P. 31 Unicorn.	1° 15′ S. P. ι Pisces.
3′ or 4′ N. of γ Gemini.	30′ N. P. θ Hydra	1° S. F. 43 Sagittarius.

V. ON TREBLE, QUADRUPLE, QUINTUPLE, AND MULTIPLE SYSTEMS OF STARS.

Dr. Herschel, with his usual ingenuity, has pointed out a variety of combinations, in which treble, quadruple, &c. stars may revolve round their common centres of gravity; but the limits, as well as the popular nature of this work, will not permit us to lay them before our readers. Several of these combinations are represented in Plate VI, *Sup.* Fig. 3, 4, 5, 6, 7, 8, 9, 10, where *a*, *b*, *c*, *d*, are the stars, and *o* their common centre of gravity. One of these combinations is so very singular, as to be peculiarly deserving of notice. Let us suppose two equal stars moving in a circular orbit round their common centre of gravity, which will be the centre of the circle. From the centre of the circle draw a line perpendicular to the plane of their orbit, extending to equal distances above and below this centre. Let us now suppose a third star to fall from one extremity of this perpendicular, from a state of rest, it will obviously descend with a gradually accelerated motion, till it reaches the centre of gravity; and passing onwards, with a motion gradually retarded, it will move to the other end of the perpendicular, where it will arrive at a state of rest, and again return, and continue to oscillate between these two points. The two stars which move in a circular orbit may describe equal ellipses of any degree of eccentricity. In this case, however, the perturbations will affect not only the planes of their orbits, but also their figures; and the length of the oscillations of the third will be sometimes increased and diminished. See Fig. 6.

The following catalogue of treble, quadruple, quintuple, sextuple, and multiple stars, is selected from the two catalogues of double stars given by Dr. Herschel.

CATALOGUE OF TREBLE, &c. STARS.

σ or 17 North Crown.

The two nearest of this treble star, are rather unequal in

magnitude, and both white. The third, with a power below 460, is very faint, and dusky in colour. The distance between the two nearest with a power of 227, is 1¼ the diameter of the larger, and with a power of 460, twice the diameter of the larger. Position 77° 32′ N. P. Distance of the third from the largest, 24″. Position 25° N. F.

12 *Lynx, below the Eye.*

The two nearest of this curious treble star are pretty unequal. The larger is white, and the smaller white inclining to a rose colour. With a power of 227, their distance is ½ the diameter of the smaller one. Position 88° 37′ S. P. The first and third are considerably unequal; the second and third pretty unequal; the colour of the third being pale red, and its distance from the first 9″ 23‴. Position with regard to the first 32° 33′ N. P.

11 *Unicorn in the left Forefoot.*

This treble star may appear double at first sight; but with a little attention one of the stars will appear double. The first or single star is the largest. The other two are smaller, and nearly equal, the preceding one being rather larger, and they are both white. The distance between the two nearest, with a power of 227, is 1 diameter of the preceding, or 1¼ the diameter of the following star. Position of the two nearest 11° 32′ S. F. Dr. Herschel considers this star as the most beautiful sight in the whole heavens.

Near 37 Eagle, the last of a Telescopic trifolium N. F. k.

The two nearest are very unequal. The third star is not visible with a power of 227. With a power of 460, the distance between the two nearest is only ½ the diameter of the larger one. The distance of the farthest is about 7″ or 8″.

ζ *or* 16 *Cancer.*

This very minute treble star requires very favourable circumstances to be distinctly seen. The two stars of which the preceding one consists are considerably unequal. The largest of these is larger than the single star, and the least of the two is less than the single star. The first and second largest are pretty unequal, and the second and third pretty unequal. The two nearest are pale red: they are just separated with a power of

278, and with 460, their distance is $\frac{1}{4}$ the diameter of the smaller one. Position 86° 32′ N. F. See ζ Cancer in the third class of double stars.

90 *Lion.*

The two nearest are very unequal. The largest is white, and the smallest reddish white. With 278, their distance is $1\frac{1}{4}$ the diameter of the largest. Position 61° 9′ S. P. The two farthest are very unequal; the smaller being dusky red. Distance from the largest 53″ 43‴. Position 35° 12′ S. P.

ξ or 51 Libra.

This star appears at first double, but the larger of the two will be found to consist of two stars. They are nearly unequal, and both white. With 460, their distance is $\frac{1}{4}$ the diameter of the larger. Position 82° 2′ N. F. See second class of double stars under ξ Libra.

About 1¾° N. F. ν Aquarius, in a line parallel to β and α Aquarius.

The two nearest are very unequal. The largest is reddish white, and the smallest pale red. With 460, their distance is about 1 diameter of the largest. Position 62° 27′ N. P. The two farthest are very unequal. The smallest is pale red. Distance with 227° 1′ 22″ 42‴. Position 35° 51′ N. F.

Preceding 70 and 67 Orion.

In a spot which appears nebulous in Dr. Herschel's finder, about 50′ from the 67th, and 45′ from the 70th Orion, there is a multiple star consisting of 12 stars, with a power of 460, and one of these is a double one. The two are considerably unequal; their distance is 1 diameter of the larger one. Position 19° 48′ S. F.

π or 42 Aries, in the ham.

The three stars which are all in a line are excessively unequal. The largest is white, and the two smallest are mere points. With 460 the distance of the two nearest is $1\frac{1}{2}$ the diameter of the largest star. The third is about 25 or 26″ from the largest. Position 19° 19′ S. F.

1¾° N. F. η Swan, in a line parallel to β and λ.

The two nearest are considerably unequal, and both pale red

With 460, their distance is 1 diameter of the small star, or $\frac{5}{4}$ that of the large one. Position 89° 18′ S. F. The two farthest are considerably unequal, and red. Position 56° 3′ N. P.

ε, or 4 or 5 Libra.

This is a remarkable double-double star, or a double star, each star being itself a double star. The first set consists of stars that are considerably unequal. The largest is very white, and the smallest reddish. Their distance with 227 is 1 diameter of the larger one. Position 56° 0′ N. F. The second set are white and equal, the preceding being rather the largest. Their distance with 227 is $1\frac{1}{2}$ the diameter of either. Position 72° 57′ S. F.

σ, or 13 Orion.

This is a double-treble star, or two sets of treble stars, almost similarly situated. The two nearest of the preceding set are equal; the third larger, and pretty unequal when compared with the latter two. With a power of 222, the distance of the two nearest is 2 diameters of either. Positions of the following star of the two nearest with the third 66° 35′, S. P. Position of the two nearest 2 or 3° N. F. or S. P. the following set. The two nearest of the following set are very unequal. The largest of the two, and the farthest, are considerably unequal, the largest being white, and the smallest bluish. With a power of 222, their distance is about $2\frac{1}{2}$ diameters of the largest. The distance of the two farthest is 43′ 12″. Position of the two nearest 5° 5′ N. F. Position of the two farthest 29° 4′ N. F.

About $2\frac{1}{2}$ following κ Aquarius, in a line parallel to α and η.

The nearest are a little unequal, and both red. Their distance with a power of 460 is $2\frac{1}{2}$ diameters of the largest. Position 25° 51′ S. P. The two farthest are a little unequal, and of the 5th class. Position about 50 or 55° S. F.

$1\frac{1}{2}$° S. F. π Orion in a line parallel to φ, and α Orion, the smallest and most southern of three forming an arch.

The two nearest are extremely unequal. The largest is a dusky white, and the smallest a mere point. Their distance with 227, is $1\frac{1}{2}$ the diameter of the larger. Position 4° 54′ N. F. The two farthest are extremely unequal. The smallest is a mere point. Position about 50 S. F.

2° Preceding the 2d and 4th of the Ship; the middle one of three.

This is a multiple star, one of them being double. The two are nearly equal, and white or ash coloured. Their distance with 227, is about 2½ diameters. Position 30° 12′ N. P. Twenty other stars are in view.

2¼′ S. F. ρ Lyra.

The two nearest are a little unequal, and both dusky red. Their distance with 460′ is 3 diameters. Position 8° 24′ N. F. The farthest is as large as the largest of the two nearest, and its colour is dusky red. Position with the largest 25° 57 S. P. Distance of ρ Lyra from the two nearest 2′ 17″ 30‴. Position 65° 12′, ρ being N. P. or the double star S. F.

¾° S. of 58 Auriga, in a line parallel to β and θ.

This is a cluster of stars containing a double star of the 2d class, and one of the 3d. The two of the second are very unequal, and both red. Their distance with 460, is 2½ diameters of the larger. Position 44° 36′ N. F. Those of the 3d class are equal, and both red. Above 20 stars are in view with 227. Distance 17″ 41‴.

1° N. P. Cup, ν towards α Lion.

The two nearest are equal, and both dusky white. Their distance with 227, is about 3 diameters. Position 71° 33′ N. F. The farthest is larger than either of the other two, and of the 6th class. Position about 68 or 69° S. P. the double star.

Star making almost an equilateral triangle with the 29th and 30th Unicorn towards the south.

Among many, the fourth from the south, and of an irregular long row, is double. The two are a little unequal, and both pale red. With 227, their distance is 1 diameter of the larger one. Position 86° 12′ S. F. Sixteen other stars are in view.

Star twice as far south of z Arrow, as z and the Star near it are from each other.

The two nearest are very unequal, and both red. Their distance with 227, is about 3 diameters of the larger. Position about 40 or 50° N. P.

A large Star 1° preceding ζ, towards 41 Swan.

The two nearest are extremely unequal. The largest is white, and the smallest pale red. Their distance with 460, is 2½ diameters of the largest. Position 45° 15′ N. P. The third and the largest are extremely unequal, and belong to the 5th or 6th class. Position about 50° S. P.

θ or 41 Orion, the small Telescopic Trapezium in the Nebula.

The stars composing this quadruple star are considerably unequal. The most southern star of the following side of the trapezium is the largest; the star in the opposite corner is the smallest, the other two being nearly equal. The largest is pale red; the star preceding the largest inclined to garnet; the star following the largest inclined to garnet; and the star opposite to the largest dusky. Distance of the two stars in the preceding side 8″.78; in the southern side 12″.84; in the following side 15″.21, and in the northern side 20″.4.

4[illegible] Orion preceding the two ι's.

The preceding set of this double-treble star consists of three equal stars, forming a triangle, and are all dusky. The distance of the two nearest with 227, is about 3 diameters. The following set consists of three stars of different sizes forming a circle. The middle star is the largest; the one to the south is pretty large, and the third is very small. The two largest are white, and the smallest pale red. Distance 36″.25.

θ or 17 Arrow.

The two nearest of this treble star are extremely unequal. The largest is pale red, the smallest dusky, and the third pale red. Distance of the two nearest 11″ 8‴. Distance of the two largest 1′ 7″ 49‴.

S. P. 1. *o Perseus.*

The equal set of this double-double star are about 4 or 5 diameters distant with 227; and the unequal set about 5 or 6 diameters.

θ, or 51 Virgin.

The two nearest are extremely unequal, the colour of the largest being white, and that of the smallest dusky. Their distance is 7″ 8‴, and their position 69° 18′ N. P. See 6th class of double stars.

1½° preceding the Tiara of Cepheus in a line parallel to ι and ζ.

The two nearest are very unequal, the larger being white, and the smaller dusky blue. Their distance is 11″ 35‴, and their position 35° 24′ S. F The two farthest are considerably unequal, the smaller being dusky blue. Their distance is 18″ 37‴, and their position 73° 57′ N. P.

1½° N. of 159 Great Bear in a line parallel to ψ and β.

The two nearest are considerably unequal, and their light red. Their distance is 12″ 30‴, and their position 0—0 preceding. The two farthest are very unequal, and the smallest dusky red. Their distance is 32′ 21‴, and their position 4° 0 N. F.

¾° N. P. 17 Swan in a line parallel to σ and α.

The two nearest of this quadruple star are extremely unequal, the largest being red, and the smallest dusky. Their distance with 625, is 13″ 54‴, and their position 67° 36′ S. F. The two largest are nearly equal, and both red. Their distance with 278, is 25″ 58‴, and their position 40° 33′ N. F.

S. P. 27 Swan, the middle of three, the most southern of which is the 27.

This star is quadruple and sextuple. In the quadruple, or N. P. set, the two nearest are very unequal. Their distance with 278 is 11″ 16‴, and their position 26° N. P. The two largest are almost equal, and both red. Distance with 278, 29″ 27‴. Position 57° 12′ N. F. In the sextuple, or S. F. set, the two largest are pretty unequal, and both red. Their distance with 278, is 19″ 20‴, and their position 27° 36′ S. F. The other stars are as small as the smallest of the quadruple set.

46, or 3. ω Swan.

The stars which compose this treble star are very unequal, and extremely unequal. The colour of the largest is fine garnet, that of the next largest red, and that of the smallest dusky. Position of the two brightest 44° 19′ N. P. They are all within 30″.

Near 27 Cepheus, near δ.

The distance of the two nearest of this treble star is about 20″.

The 1st of 2 Stars preceding ε in the Eagle.

The distance of the two nearest is 21″ 30‴.

2° N. P. H Gemini in a line parallel to the 65 Orion, and ζ Taurus, the middle one of three.

The stars of this quintuple star are in the form of a cross. The two nearest, or the preceding of the five, are extremely unequal. Distance 20″ 57‴. Position 7° 27′ S. P. There is a very obscure star of the third class near the last of the three, in the obscure star of the cross. Other five stars are dispersed about the quintuple one.

The last Star of the Lizard

The two nearest are extremely unequal, the larger being reddish white, and the smaller dusky. Their distance is 20″ 27‴, and their position 79° 33′ N. P. The next are very unequal, the smaller being red. Distance 64″ 57‴. Position 44° 24′ N. F.

8 Lizard in the middle of the tail.

The two largest and nearest of this quadruple star are a little unequal, and both reddish white. Their distance is 17″ 14‴, and their position 84° 30′ S. P. The two next are very unequal, and of the fourth class; and the other two considerably unequal, and of the 5th class.

Between β and ζ Dolphin, but nearer to β.

All the three stars are whitish red, and nearly equal. Distance of the two nearest with 278, 21″ 33‴. Position 18° 27′ N P.

About 2½ preceding 25 Unicorn.

This quadruple star consists of two large stars that can always be seen, and of other two that are visible only in dark nights. The nearest are extremely unequal, and their distance 20″ 27‴.

Of a Trapezium in the Arrow, consisting of this Treble Star, δ, ζ and 9, it is the Star opposite to ζ and nearest to ζ of two.

The two nearest are very unequal, the largest being pale red, and the smallest dusky blue. Their distance is 21″ 22‴ and their position 0° F. The two largest are a little unequal, and of the 5th class. Position 10° 36′ S. P.

χ or 13 Arrow, the largest of three.

The two nearest are equal and red. Their distance is 23″ 2‴,

and their position is 10° 12′ S. P. The third is a large star, about 1 minute distant, having a position of 10° or 15° N. P. the other two.

β or 10 *Lyra.*

The stars of this quadruple star are all white, the 2d, 3d, and 4th inclining to red. The 1st and 2d are considerably unequal. The 1st and 3d very unequal, and the 1st and 4th very unequal. Distance of the first and second, 43″ 57‴. Position 60° 28′ S. F.

μ or 13 *Sagittarius.*

Distance of the nearest about 30″.

A spot over the right forefoot of the Unicorn.

This spot contains 4 or 5 small stars within one minute.

λ or 15 *Auriga.*

Two of this multiple star are within 30″.

υ or 18 *Crown.*

The stars of this treble star are very unequal. The largest is white, and the two smallest both red. Distance of the nearest 50″.

69 *Swan.*

The stars of this treble star are very unequal. The largest is white, and the two smallest both reddish.

A small Star near the place of 12 *Gemini.*

The two nearest are a little unequal, and distant about 1 minute.

1° *N. F.* 9 *Orion, towards* 113 *Taurus, the largest of two.*

The two nearest are considerably unequal, and reddish white. Their distance with 278, is 36″ 26‴, and their position 33° 36′. The two farthest are very unequal. The smallest being red, and belonging to the 9th class.

17 *or* 2 *π Great Dog.*

The three stars form a right angled triangle, the hypothenuse of which contains the largest and smallest. The two nearest are very unequal, the largest being reddish white, and the smallest red. Their distance is 44″ 52‴, and their position

64° 12′ S. F. The two farthest are very unequal, the smallest being red, and belonging to the 5th class. Position about 85° S. P.

One of two Stars N. P. the 75th, in a line parallel to the 84th and 59th Lion.

The two nearest are very unequal; their distance is 54″ 37‴. The two farthest are extremely unequal.

12 *Great Bear.*

The stars are extremely unequal, and all red. The nearest is the smallest Position some degrees S. F.

1° *S. P. the* 11 *Orion, towards ι Taurus.*

The two nearest are considerably unequal, the largest being white, and the smallest pale red. Distance 37″ 51‴. Position 33° 54′ N. P. The third is farther off, smaller, red, and N. F.

41 *Aries.*

The two nearest are excessively unequal. The largest is white, and the smallest is faint. Their distance with 278, is 39″ 20‴, and their position 80° 48′ S. P.

ν, or 8 *Lyra.*

The stars are extremely unequal, the largest being white, and the other two dusky. Distance of the following star, 56″ 47‴. Position 28° 27′ S. F.

χ Perseus.

Dr. Herschel counted no fewer than forty stars within his small field of view.

d, or 4 *Cassiopeia.*

The distance of the two large ones is about 2′, and that of the 3d, which is obscure, 1¾′. The three form nearly a right-angled triangle.

β, or 78 *Gemini.*

The stars of this multiple star are extremely unequal. The nearest distance is 1′ 56-45‴. Position 24° 28′, N. F. The next distance is 3′ 17″ 19‴, and the position 15° 56′ N. F.

Star preceding b Pisces.

The stars form a triangle, each side of which is about 1 minute.

In the Unicorn's Head.

This multiple star consists of 1 star, with about 12 around it.

o, or 70 Gemini.

The distance of the nearest is a little more than 1 minute, and that of the farthest not much more.

14 Great Dog.

The nearest are extremely unequal, the largest being reddish white, and the smallest dusky. Their distance is 1′ 5″ 28‴, and their position 26° 24′ N. F.

ζ or 44 Perseus.

The nearest are extremely unequal, the largest being white, and the smallest red. Their distance is 1′ 11″ 26‴, and their position 66° 36′ S. P. The farthest are very unequal, the smallest being red, and about 1½′ distant. Position 70° or 75° S. P.

δ or 68 Taurus.

This star has other two in view. The nearest are excessively unequal, the largest being white, and the smallest dusky. Their distance with 278 is 1′ 3″ 18‴, and their position 35° 21 S. P. The farthest are extremely unequal, the smallest being red, and about 1½′ distant. Position 50° N. P.

α, or 30 Hydra.

This star has two within about 2′. The nearest are excessively unequal, and the farthest extremely unequal. Both S. F.

VI. ON CLUSTERING STARS AND THE MILKY WAY.

By examining the stars that are scattered over the milky way, it will appear that they are unequally dispersed, and that they cluster together into many separate allotments. In the space, for example, between β and γ Swan, the stars are clustering with a kind of division between them, so that they may be considered as clustering towards two different regions. Dr. Herschel found from observation, that the space in question, taking an average breadth of about 5° of it, contains more than 331,000 stars, which gives 165,000 for each clustering collection. These clustering collections are brighter about the middle, and fainter near their undefined borders.

The milky way is a luminous zone which makes a complete circle in the heavens. It traverses the constellations Cassiopeia, Perseus, Auriga, the east arm of Aries, the feet of Gemini, a part of the Great Dog, the middle of the ship, where it is most luminous, the Centaur, the Cross, the Southern Triangle, the Altar, the tail of Scorpio, the bow of Sagittarius, a part of Ophiuchus, where it separates into two branches, and again unites, the shield of Sobieski, the tail of the Serpent, the Eagle, the Arrow, the Fox and Goose, the Swan, and the head of Cepheus.

On the Milky Way.

Dr. Herschel has found, from numerous observations, that the brightness of the Milky Way is owing solely to small stars; and that the compression of the stars increases in proportion to the brightness of the Milky Way.

In order to account for this singular zone of stars, Dr. Herschel supposes, that the Milky Way is a large nebula, in the inside of which the Sun is placed, but not in the centre of its thickness. The Milky Way, therefore, according to this hypothesis, is the projection of the nebula upon the concave surface of the sky, as seen from a point within it. Thus, if the solar system be supposed at S, in the middle of the nebula *a b c d e f*, with two branches *a c*, *b c*, the nebula will be projected into a circle A B C D, the arches A B C, A E C being the projection of the branches, *a c*, *b c*.

Plate VI. *Sup.* Fig. 11.

In order to ascertain the place which the Sun occupies in this nebula, and the form of the nebula itself, Dr. Herschel has put in practice a method which he calls *guaging the heavens*, and which consists in repeatedly counting the number of stars in ten fields of view very near each other. By adding the numbers of stars in each field, and cutting off a decimal, he obtains a mean of the number of stars in that part of the heavens. Dr. Herschel then supposes, that the stars are equally scattered; and from the number of stars in any part of the heavens, he deduces the length of his *visual ray*, or the distance through which his telescope has penetrated, or, what is the same thing, the distance of the remotest stars in that particular portion of the heavens. In order to understand this, let us suppose, that the Milky Way is a nebula, and that the solar system is not in its centre: Then, upon the supposition that the stars are equally scattered, it is obvious, that the part of the Milky Way where the stars are most numerous must extend farthest from the solar

system, and *vice versa*. Proceeding in this way, Dr. Herschel has found the length of his visual ray for different parts of the heavens, which, in some cases, is equal to 497 times the distance of the nearest fixed star, and he has delineated the section of the nebula forming the Milky Way, as represented in Fig. 7, Plate V, *Sup.* This section makes an angle of 35° with our equator, crossing it in 124½ and 304½ degrees of R. ascension. The horizon of a celestial globe, rectified to the latitude of 55° N. and having σ Ceti on the meridian, will represent the plane of this section. If the solar system is at S, the brightness of the Milky Way will be greatest in the directions S *a*, S *b*, S *p*, where the stars that intervene are most numerous, or where the visual ray is longest. In the lateral directions S *m*, S *n*, the nebulosity will not appear from the small number of interposing stars; and in the direction S *c*, on account of the opening between *a* and *b*, there will be an empty space contained between these two branches, where the nebulosity is not observed, as is the case in the Milky Way between μ Scorpio in the south and γ Cygni in the north, a length of about 102 degrees. The circle in Fig. 7 described round S, is at 40 times the distance of the nearest fixed stars, and probably comprehends all those that are visible to the naked eye.

Dr. Herschel, therefore, considers the Milky Way as a *very extensive branching congeries of many millions of stars*, which probably owes its origin to several remarkably large, as well as pretty closely scattered small stars, that may have drawn together the rest. He supposes, that there are many parts of the Milky Way where the stars are drawing towards secondary centres, and may in time separate into different clusters. Some parts of the Milky Way, he imagines, have suffered greater ravages than others, and particularly that part of it in the body of Scorpio, where there is a large opening or hole, about 4 degrees broad, and almost destitute of stars. The stars which once filled this vacancy, he supposes to have formed the 8th nebula in the *Connoisance des Temps*, which is a rich cluster of small stars, and is just upon the western border of the opening.

In looking out at the sides of the nebula of the Milky Way towards Leo, Virgo, and Berenice's Hair, on the one side, and towards Cetus, on the other, where the intervening stars are very few, Dr. Herschel observed a remarkable purity or clearness in the heavens; whereas the ground of the heavens became

troubled towards the length or height of the nebula. The troubled parts arise from some distant straggling stars, which can scarcely be distinguished, but which Dr. Herschel has discovered after long examination.

There are several other nebulæ in the heavens as large as that of the Milky Way, and which will, therefore, exhibit the phenomenon of a lucid zone to the planetary worlds that may be placed within them.

VII. ON GROUPS OF STARS.

Groups of stars succeed to clustering stars in Dr. Herschel's arrangement. A group is a collection of stars closely, and almost equally, compressed, and of any figure or outline. There is no particular condensation of the stars to indicate the existence of a central force, and the groups are sufficiently separated from neighbouring stars to shew that they form peculiar systems of their own.

VIII. ON CLUSTERS OF STARS.

Dr. Herschel regards clusters of stars as the most magnificent objects in the heavens. They differ from groups in their beautiful and artificial arrangement. Their form is generally round, and their condensation is such as to produce a mottled lustre, somewhat resembling a nucleus. The whole appearance of a cluster indicates the existence of a central force residing either in a central body, or in the centre of gravity of the whole system.

The following Catalogue, collected from Dr. Herschel's papers, contains the position of 109 clusters of stars, divided into two classes. The *first* column contains the number of the cluster; the *second*, the star near which it is placed; the *third*, its distance preceding or following that star; and the *fourth*, its distance north or south of the star; and the *fifth*, its magnitude in minutes. Thus, the 1st cluster in the catalogue is near *p* Gemini. Its right ascension is 10 greater, or it follows the star at the distance of 10 minutes in time; and its declination is 12′ north of the star.

Catalogue of Clusters of Stars, from the Observations of Dr. Herschel.

I. *Compressed and Rich Clusters of Stars.*

Numbers.	Stars by which the clusters may be found.	Diff. of R. Ascension in time between the cluster and the star.			Difference in Declination.			Diameter in minutes.
1	*p* Gemin.	10	0	F.	0	12	N.	12
2	ι Gemin.	27	10	F.	2	9	S.	5
3	12 Monocer.	11	30	F.	0	18	S.	
4	4 Sextant.	5	30	F.	0	5	S.	
5	2 ξ Gem.	31	0	P.	0	15	S.	7
6	67 Gemin.	18	0	P.	1	57	S.	
7	42 Com. Ber.	8	30	F.	0	8	N.	10
8	χ Virg.	23	44	F.	0	6	S.	8
9	11 Bootes	4	18	F.	1	7	N.	6
10	Antares	1	48	P.	0	24	N.	
11	39 Ophiuchi	13	24	P.	0	26	S.	
12	43 Ophiuchi	12	42	P.	1	36	N.	
13	γ Sagittæ	14	48	P.	0	18	N.	5
14	9 Vulpec.	4	0	P.	0	33	N.	4 by 2
15	34 σ Sagittæ	6	54	P.	0	27	N.	
16	12 γ Sagittæ	4	18	P.	1	32	S.	
17	42 ι ω Gem.	54	53	P.	0	29	S.	4
18	11 Monocer.	27	15	F.	0	2	S.	8
19	24 1 ι Libræ	5	0	F.	1	16	S.	6
20	18 ι Pisc. Aust.	133	24	F.	0	23	N.	3
21	25 Gemin.	2	15	F.	1	15	S.	5
22	31 Monocer.	30	4	P.	1	20	N.	11
23	46 υ Sagitt.	49	15	P.	0	42	S.	15
24	58 ν Cygni	15	56	F.	1	18	N.	6 by 4
25	27 κ Persei	5	55	F.	2	25	N.	7
26	53 *d* Persei	13	34	F.	1	13	S.	4
27	22 Monocer.	20	9	P.	0	51	N.	20
28	75 *l* Leonis	21	25	F.	1	2	N.	
29	3 Lacertæ	7	52	P.	2	7	N.	
30	7 ρ Cassiop.	3	10	F.	0	46	S.	
31	37 δ Cassiop.	19	48	F.	1	2	N.	15
32	80 1 π Cygni	11	26	P.	0	28	N.	8
33	7 χ Persei	1	7	F.	0	22	S.	
34	7 χ Persei	4	0	F.	0	23	S.	30
35	15 κ Cassiop.	1	22	P.	1	26	S.	1
36	6 Navis	8	45	P.	1	55	S.	8 by 2
37	26 Hydræ	79	30	P.	1	0	N.	5
38	50 γ Aquilæ	14	50	P.	1	18	S.	
39	ζ Pixidis Naut.	20	39	P.	0	19	S.	
40	53 ν Serpent.	48	17	P.	0	2	N.	5
41	35 Draconis	22	6	P.	1	7	S.	3
42	3 η Cepheus	13	26	P.	1	6	S.	8

II. Pretty much compressed Clusters of Large or Small Stars.

1	90 1 c Tauri	11	0	F.	1	30	S.	11
2	8 Monocer.	8	17	F.	0	23	N.	
3	3 Leporis	72	30	P.	0	30	S.	
4	15 2 y Orion	3	6	F.	1	10	N.	22
5	13 Monocer.	3	15	P.	0	28	S.	
6	50 Gemin.	3	55	F.	2	9	S.	
7	3 p Sagitt.	15	54	F.	0	8	S.	
8	41 i Cygni	5	42	P.	2	1	S.	20
9	12 Vulpec.	0	5	P.	0	30	N.	
10	7 ξ Navis	5	56	F.	0	40	N.	15
11	19 Navis	0	40	P.	0	5	N.	20
12	6 Navis	31	59	P.	1	25	N.	30
13	2 β Canis	7	10	P.	0	44	S.	15
14	18 μ Canis	3	17	F.	0	20	N.	20
15	26 Canis	1	22	F.	1	52	N.	
16	———	1	56	F.	0	16	N.	20
17	———	6	26	P.	1	1	N.	
18	12 Vulpec.	7	56	P.	0	44	N.	
19	21 Aquilæ	5	49	P.	1	55	N.	13
20	7 Monocer.	1	3	F.	0	35	N.	11
21	109 n Tauri.	14	59	P.	1	37	N.	
22	13 Monocer.	2	48	P.	0	21	N.	
23	31 η Canis	32	6	P.	0	39	S.	
24	60 Orion	5	9	P.	0	9	S.	7
25	8 Monocer.	11	46	P.	0	49	N.	4
26	6 Monocer.	8	59	F.	1	7	N.	
27	11 ———	42	13	F.	1	21	S.	9 by 5
28	2 Navis	8	23	P.	0	47	N.	15
29	5 ρ Scorp.	7	14	P.	0	38	N.	6 by 4
30	14 Sagittar.	1	35	P.	0	9	N.	15
31	———	1	29	F.	0	25	S.	2
32	58 Androm.	10	49	P.	0	8	S.	30
33	11 m Aurig.	6	32	F.	0	54	N.	
34	13 α ———	9	7	F.	0	32	N.	3
35	70 ξ Orion	15	53	F.	1	29	S.	
36	18 Monocer.	3	48	P.	1	0	N.	
37	77 Orion	12	24	P.	0	55	N.	3
38	22 Monocer.	7	39	P.	1	31	N.	11
39	21 σ Aurig.	3	25	F.	2	6	S.	4
40	3 Lacertæ	38	31	P.	1	35	N.	4
41	———	5	8	F.	0	2	N.	4
42	24 η Cassiop.	29	41	F.	0	26	N.	
43	1 e ———	11	41	P.	1	25	N.	
44	———	4	34	F.	1	8	N.	
45	37 δ ———	9	29	P.	1	28	S.	
46	———	17	23	F.	1	44	N.	
47	10 Camelop.	55	40	P.	1	37	N.	3
48	32 Cassiop.	17	1	F.	1	40	S.	6
49	45 ι ———	11	8	P.	0	20	N.	3
50	81 2 π Cygni	22	13	P.	1	14	S.	
51	71 g ———	5	49	P.	0	9	S.	5

52	————	0 42	P.	0 34	N.	20
53	73 ϱ ————	30 41	F.	0 48	N.	
54	36 Camelop.	29 1	F.	0 16	N.	
55	32 ι Cephei	57 35	F.	1 47	N.	
56	11 β Cassiop.	9 57	P.	2 6	N.	5
57	40 Aurigæ	8 28	F.	1 25	N.	6
58	6 Navis	5 18	F.	0 29	S.	7
59	18 δ Cygni	18 38	F.	1 4	S.	15
60	47 λ Persei	3 30	F.	0 50	S.	7
61	41 Persei *Hev.*	3 8	P.	0 56	N.	15
62	19 Aquilæ	0 26	P.	1 24	S.	
63	ζ Pixid Naut.	2 25	P.	0 24	S.	
64	————	20 55	P.	1 9	S.	
65	2 Navis	16 10	P.	0 38	N.	
66	7 Cephei	16 45	F.	1 7	S	12
67	15 π Canis	42 33	F.	0 14	S.	

IX. OF NEBULÆ.

According to Dr. Herschel, nebulæ may, perhaps, be resolved into the three last-mentioned classes. Collections of clustering stars, when removed to a sufficient distance, may have the appearance of a nebula of any shape, and will seem to be gradually brighter in the middle. Groups of stars may also, at a great distance, resemble nebulæ; and clusters of stars that cannot be resolved by the most powerful telescopes, will appear like round nebulæ, increasing in brightness towards the centre.

Mr. Michell has shown, from the computation of probabilities, that it is many million million chances to one, that the stars which appear to form double stars, &c. clusters and nebulæ in the heavens, are really collected together into separate systems. In the case of the Pleiades, for example, he computes that it is 500,000 to 1, that no six stars out of the number of those that are equal to the faintest of them in splendour, scattered at random in the whole heavens, should be within so small a distance from each other as the Pleiades are.

A similar opinion was maintained by Professor Kant and M. Lambert, who supposed, that all the stars in the universe are collected into nebulæ; and that all the insulated or scattered stars which appear in the heavens, belong to the particular nebula in which our system is placed. We are indebted, however, solely to the genius and industry of Dr. Herschel, for perfecting these sagacious views, and supporting them by a body of evidence amounting nearly to demonstration. He has observed the position, magnitude, and structure of no fewer than 2,500

nebulæ. He generally detected them in certain directions, rather than in others; and in many parts of the heavens there were vacant spaces, both preceding and following the nebulous strata. Dr. Herschel supposes the nebula in Cancer, and that of Coma Berenicis, to belong to two strata which are nearest the nebula of the Milky Way

The following Catalogue of Nebulæ is founded chiefly on the observations of Messier, as given in the *Connoisance des Temps* in 1784, the more recent observations of Dr. Herschel being always added. The *first* column contains the number of the nebula, and the time when the observation was made; the *second* and *third*, its right ascension and declination for that time, which are more convenient than their longitude and latitude for finding them on a celestial globe. The *fourth*, its diameter in degrees and minutes; and the *last*, some general remarks on its appearance. All the nebulæ in this class may be seen with good telescopes of a moderate rate.

CATALOGUE of 103 Nebulæ, the Positions of which have been determined by Messier.

No. and year when observed.	Position of the Nebulæ.	Right Ascen. in degrees.	Declination.	Diameter.
1758				
1	Above the Bull's southern horn, west of ζ,[a]	80 0 33	21 45 27 N.	
1760				
2	In head of Aquarius, near the 24th star,[b]	320 17 0	1 47 0 S.	4′
1764				
3	Between Arcturus and Cor Caroli,[c]	202 51 19	29 32 57 N.	3
4	Near Antares,[d]	242 16 56	25 55 40 S.	2½
5	Near 6 Serpent,[e]	226 39 4	2 57 16 N.	3
6	Between bow of Sagit. and tail of Scorpio,[f]	261 10 39	32 10 34 S.	15
7	Near the preceding,[f]	264 30 24	34 40 34 S.	30

[a] A whitish light elongated like the flame of a taper. It exhibited a mottled nebulosity to Dr. Herschel.

[b] It is like the nucleus of a comet, surrounded with a large round nebula. Dr. H. resolved it into stars.

[c] It is round, bright in the centre, and fades away gradually. It exhibited a mottled nebulosity to Dr. H.

[d] A mass of small stars.

[e] A round nebula. Resolved into stars by Dr. H.

[f] A mass of small stars.

8	Between bow of Sagittarius, and right foot of Ophiuchus,[g]	267 29 30	24 21 10 s.	30′
9	In the right leg of Ophiuchus,[h]	256 20 36	18 13 26 s	3
10	In the girdle near 30 Ophiuchus,[i]	251 12 6	3 42 18 s.	4
11	Near K. Antinous,[k]	279 35 43	6 31 1 s.	4
12	Between arm and left side of Ophiuchus,[l]	248 43 10	2 30 28 s.	3
13	In the girdle of Hercules, between 2 stars of the 8th mag.[m]	248 18 48	36 54 44 N.	6
14	In the drapery over the R. arm of Ophiuchus,[n]	261 18 29	3 5 45 s.	7
15	Between the head of Pegasus and that of the Little Horse,[o]	319 40 19	10 40 3 N.	3
16	Near the Serpent's tail,[p]	271 15 3	13 51 44 N.	8
17	North of bow of Sagit.[q]	271 45 48	16 14 44 s.	5
18	Above the preceding,[r]	271 34 3	17 13 14 s.	5
19	Between Scorpio and R. foot of Ophiuchus,[s]	252 1 45	25 54 46 s.	3
20	Between bow of Sagit. and R. foot of Ophiuchus,[t]	267 4 5	22 59 10 s.	
21	Near 11 Sagittarius,[t]	267 31 35	22 31 25 s.	6
22	Near 25 Sagittarius,[u]	275 28 39	24 6 11 s.	15
23	Near 65 Ophiuchus,[x]	265 42 50	18 45 55 s.	1° 30
24	Near end of bow of Sagit. in Milky Way,[y]	270 26 0	18 26 0 s.	
25	Near preceding; near 21 Sagittarius,[t]	274 25 0	19 5 0 s.	10
26	Near *n* and *o* Antinous,[z]	278 5 25	9 38 14 s.	2

[g] An elongated mass of stars. Near this mass is the 9 of Sagittarius, which is encircled with a faint light.

[h] Round and faint; but resolved by Dr. H. into stars.

[i] A fine and round nebula. Resolved into stars by Dr. H.

[k] A mass of many small stars mixed with a faint light.

[l] Round and faint. Near it is a star of the 9th mag. Resolved by Dr. H. into stars.

[m] Round and bright in the middle. Resolved by Dr. H. into stars.

[n] Round and faint. Near a star of the 9th mag. Resolved into stars by Dr. H.

[o] Round and bright in the centre. Resolved into stars by Dr. H.

[p] A mass of small stars, mixed with a faint light. Resolved by Dr. H.

[q] A train of faint light with stars.

[r] A mass of small stars surrounded with nebulosity.

[s] Round, and resolved into stars by Dr. H.

[t] A mass of stars of the 8th and 9th mag. surrounded by nebulosity.

[u] Round, and resolved into stars by Dr. H.

[x] A mass of stars very near each other.

[y] Great nebulosity, containing several stars. The light is divided into several parts. Resolved into stars by Dr. H.

[z] A mass of small stars.

27	Near 14 of the Fox,[a]	297	21	41	22	4	0 N.		4
28	A degree from λ Sagittarius,[b]	272	29	30	24	57	11 S.		2
29	Below γ Cygni,[c]	303	54	29	37	11	57 N.		
30	Near 41 Capricorn,[d]	321	46	18	24	19	4 S.		2
31	In Andromeda's girdle,[e]	7	26	32	39	9	32 N.		40
32	Below the preceding,[f]	7	27	32	38	45	34 N.		2
33	Below the head of the N. Fish and the Great Triangle,[g]	20	9	17	29	32	23 N.		15
34	Between Medusa's head and the left foot of Andromeda,[h]	36	51	37	41	39	32 N.		15
35	Near μ and η Castor,[i]	88	40	9	24	33	30 N.		20
36	Near φ Bootes,[k]	80	11	42	34	8	6 N.		9
37	Near the preceding,[l]	84	15	12	32	11	51 N.		9
38	Near σ Auriga,[m]	78	10	12	36	11	51 N.		
39	Near the Swan's tail,[n]	320	57	10	47	25	0 N.		15
40	At the root of the Great Bear's tail,[o]	182	45	30	59	23	50 N.	1°	0
41	Below Sirius,[p]	98	58	12	20	33	0 S.		
1765									
42	Between θ and c in Orion's sword,[q]	80	59	40	5	34	6 S.		6
1769									
43	Above the preceding,[r]	81	3	0	5	26	37 S.		
44	Between γ and δ Cancer,[s]	126	50	30	20	31	38 N.		
45	The Pleiades,[t]	53	27	4	23	22	41 N.		
46	Between the G. Dog's head and the hind feet								
1771	of the Unicorn,[u]	112	47	43	14	19	7 S.		
47	Near the preceding,[x]	116	3	58	14	50	8 S.		
48	Near the three stars at root of Unicorn's tail,[z]	120	36	0	1	16	42 S.		
49	Near ρ Virgo,[y]	184	26	58	9	16	9 N.		

[a] Oval. It exhibited a mottled nebulosity to Dr. H.
[b] Round, and resolved into stars by Dr. H. [c] A mass of 7 or 8 small stars.
[d] Round, and resolved into stars by Dr. H.
[e] It resembles two cones of light joined at their base, which is 15′ broad Resolved into stars by Dr. H.
[f] Round, without stars, and with a faint light.
[g] Its light is uniform and whitish. It exhibited a mottled nebulosity to Dr. H.
[h] A mass of small stars. [i] A mass of small stars near Castor's left foot.
[k] A mass of small stars.
[l] A mass of small stars, with a nebulosity. Resolved into stars by Dr. H.
[m] A square mass of small stars. [n] A mass of small stars.
[o] Two stars very near one another. [p] A mass of small stars.
[q] A beautiful nebula, containing 7 small stars. See Plate VI, *Sup.* Fig. 12,
[r] A star surrounded with nebulosity. [s] A mass of small stars.
[t] Cluster of stars. [u] A mass of stars, with a little nebulosity.
[z] A mass of small stars. [y] See *Mem. Acad.* 1779.

50	Above θ Great Dog,[z]	102 57 28	7 57 42 S.	
1772				
51	Below η Great Bear, Near the ear of the Northern Greyh.[a]	200 5 48	48 24 24 N.	
1774				
52	Below *d* Cassiopeia,[b]	348 39 27	60 22 12 N.	
53	Near 42 Berenice's hair,[c]	195 30 26	19 22 44 N.	
1777				
54	In Sagittarius,[d]	280 12 55	30 44 1 S.	6′
1778				
55	In Sagittarius,[e]	291 30 25	31 26 27 S.	
56	Near the Milky Way,[f]	287 0 1	29 48 14 N.	
1779				
57	Between γ and β Lyra,[g]	281 20 8	32 46 3 N.	
58	In Virgo,[h]	186 37 23	13 2 42 N.	
59	Near the preceding,[h]	187 41 38	12 52 36 N.	
60	In Virgo,[i]	188 6 53	12 46 2 N.	
61	In Virgo,[k]	182 41 5	5 42 5 N.	
62	In Scorpio,[l]	251 48 24	29 45 30 S.	
63	In the Canes Venatici,[m]	196 5 30	43 12 37 N.	
1780				
64	In Berenice's hair,[n]	191 27 38	22 52 31 N.	
65	In the Lion,[o]	166 50 54	14 16 8 N.	
66	Very near preceding,[p]	167 11 39	14 12 21 N.	
67	Below the southern claw of the Crab,[q]	129 6 57	12 36 38 N.	
68	Below the Crow,[r]	186 54 33	25 30 20 S.	2
69	Below the left arm of Sagittarius,[s]	274 11 46	32 31 45 S.	2
70	Near the preceding,[t]	277 13 16	32 31 7 S.	2
71	Between γ and δ Arrow,[u]	295 59 9	18 13 0 N.	3′ 30″

[z] Mass of small stars below Unicorn's right thigh.

[a] Double. The two atmospheres, whose centres are 4′ 35″ distant, touch one another, and are bright in the middle. The one is fainter than the other. Resolved iuto stars by Dr. H.

[b] Mass of stars, mixed with a nebulosity, according to Dr. H. This cluster appears like a solid ball, consisting of small stars, quite compressed into one blaze of light, with a great number of loose ones surrounding it. See Plate V, *Sup.* Fig. 10.

[c] Round, and resolved into stars by Dr. H.

[d] Faint, and bright in the centre.

[e] A white spot. Resolved into stars by Dr. H.

[f] Faint, and resolved into stars by Dr. H.

[g] Round, and consisting of a mottled nebulosity.

[h] Very faint, without any star.

[i] Brighter than the two preceding.

[k] Very faint.

[l] Like a comet, with a brilliant centre, surrounded with a faint light. Resolved into stars by Dr. H.

[m] Very faint.

[n] Faint.

[o] Faint, but resolved into stars by Dr. H.

[p] Very faint, but resolved into stars by Dr. H.

[q] A mass of stars, with nebulosity. It is a cluster, pretty much compressed, in which Dr. H. has observed 200 stars at once, with a power of 157.

[r] Very faint.

[s] Faint, like the nucleus of a small comet.

[t] Near four telescopic stars.

[u] Very faint, and resolved into stars by Dr. H.

72	Above tail of Capricorn,[x]	310 20 49	13 20 51 s.	2′
73	Near the preceding,[y]	311 43 4	13 28 40 s.	
74	Near η in the string that connects the Fishes,[z]	21 14 9	14 39 35 N.	
75	Between Sagittarius and head of Capricorn,[a]	298 17 24	22 32 23 s.	
76	In Andromeda's right foot,[b]	22 10 47	50 28 48 N.	2
77	In the Whale,[c]	37 52 33	0 57 43 s.	
78	In Orion,[d]	83 53 35	0 1 23 s.	3
79	Below the hare,[e]	78 49 2	24 42 57 s.	
80	Between g & δ Scorpio,[f]	240 59 48	22 25 13 s.	2
1781				
81	Near the ear of G. Bear,[g]	144 27 44	70 7 24 N.	
82	Near the preceding,[h]	144 29 22	70 44 27 N.	
83	Near Centaur's head,[i]	201 8 13	28 42 27 s.	
84	In Virgo,[k]	183 30 21	14 7 1 N.	
85	Above and near Spica,[l]	183 35 21	19 24 26 N.	
86	In Virgo,[m]	183 46 21	14 9 52 N.	
87	In Virgo,[n]	184 57 6	13 38 1 N.	
88	In Virgo,[o]	185 15 49	15 37 51 N.	
89	Near No. 87,[p]	186 9 36	13 46 49 N.	
90	In Virgo,[p]	186 27 0	14 22 50 N.	
91	Above the preceding,[q]	186 37 0	14 57 6 N.	
92	Between the knee and left leg of Hercules,[r]	257 38 3	43 21 59 N.	5
93	Between the Great Dog and the Ship,[s]	113 48 35	23 19 45 s.	8
94	Above Cor Caroli,[t]	190 10 46	42 18 43 N.	2′ 30″
95	In the Lion, above l,[u]	158 3 5	12 50 21 N.	
96	Near the preceding,[x]	158 46 20	12 58 9 N.	
97	Near β Great Bear,[y]	165 18 40	56 13 30 s.	2

[x] Faint, but resolved into stars by Dr. H.
[y] Three or four small stars, containing a little nebulosity.
[z] Very faint, but resolved into stars by Dr. H.
[a] Composed of small stars, with nebulosity. Mechain makes it only nebulous.
[b] Composed of small stars, with nebulosity. Small and faint.
[c] A mass of small stars, containing nebulosity.
[d] A mass of stars, with two bright nuclei, surrounded with a nebulosity.
[e] A fine nebula, bright in the centre, and a little diffused. Resolved into a mottled nebulosity by Dr. H. [f] Round and bright in the centre, like a comet.
[g] A little oval, bright in the centre, and exhibiting a mottled nebulosity to Dr. H.
[h] Faint and elongated, with a telescopic star at its extremity. It shews a mottled nebulosity to Dr. H. [i] Very faint.
[k] Bright in the centre, and surrounded with nebulosity. [l] Very faint.
[m] The same as No. 84, and near it. [n] As luminous as the preceding.
[o] Very faint, and like No. 58. [p] Very faint.
[q] Fainter than the preceding.
[r] A beautiful nebula, bright in the centre, and surrounded with great nebulosity. Resolved into stars by Dr. H. [s] A mass of small stars.
[t] Bright in the centre, with a diffused nebulosity. [u] Very faint.
[x] Fainter than the preceding.
[y] Very faint. Another near it, and another near γ.

98	Above N. wing of Virgo,[a]	180 50 49	16 8 15 N.	
99	On N. wing of Virgo,[a]	181 55 19	15 37 12 N.	
100	In ear of corn in Virgo,[a]	182 59 19	16 59 21 N.	
101	Between left hand of Bootes and the tail of the Great Bear,[b]	208 52 4	55 24 25 N.	7′
102	Between ο Bootes and ι Dragon,[c]			
103	Between ι and δ Cassiopeia,[d]			

[a] Very faint.
[a] Brighter than the preceding. Between two stars of the 7th and 8th mag.
[b] Very faint. Discovered by Mechain. Mottled nebulosity, according to Dr. Herschel. [c] Very faint, discovered by Mechain. [d] A mass of stars.

Dr. Herschel has divided the nebulæ which he has observed into eight classes, viz. 1. Bright nebulæ. 2. Faint nebulæ. 3. Very faint nebulæ. 4. Planetary nebulæ. 5. Very large nebulæ. 6. Compressed clusters of stars. 7. Pretty much compressed clusters of large or small stars. And, 8. Coarsely scattered clusters of stars.

In the following Catalogue we have given the whole of Dr. Herschel's first class, amounting to 288, being those which may be most readily seen by ordinary telescopes. It does not include any that are given in the preceding catalogue. Our limits will not permit us to give Dr. Herschel's remarks upon the nature of each nebula. We have therefore confined the catalogue solely to their position in the heavens. The letter F. signifies following, and P. preceding, S. south, and N. north.

		M.	S.	D.	M.
80		67	10 F.	0	46 N.
81	41 Leonis min.	0	6 P.	1	40 N.
82	14 *b* Comæ,	37	40 P.	0	14 S.
83	21 *g* Comæ,	0	10 F.	1	12 N.
84		19	34 F.	0	55 N.
85	40 Comæ,	5	9 F.	0	18 N.
86	39 Leonis min.	13	14 P.	0	59 N.
87	44 Leonis min.	9	30 F.	1	1 N.
88		13	30 F.	0	1 N.
89	14 *b* Comæ,	8	18 P.	0	55 N.
90		6	30 P.	1	57 N.
91	15 *c* Comæ,	1	10 F.	0	19 N.
92		9	8 F.	0	19 S.
93	31 Comæ,	2	56 F.	1	24 N.
94	61 Ursæ,	0	6 F.	2	17 N.
95		35	0 F.	2	7 N.
96	14 Canum,	5	30 F.	1	12 N.
97		7	58 F.	0	47 N.
98		36	50 F.	0	12 S.
99	27 γ Bootes,	13	46 P.	1	46 S.
100	41 Ceti,	13	43 F.	0	48 N.
101	67,	17	19 P.	0	25 N.
102		21	37 F.	0	13 S.
103	14 Delphini,	16	10 P.	0	3 S.
104	93 ψ Aqua,	1	8 F.	0	42 N.
105	47 Ceti,	26	24 F.	0	37 S.
106	89 π,	38	10 F.	1	24 S.
107	20 Eridani,	4	3 F.	1	4 S.
108	111 ξ Piscium,	34	22 P.	0	1 S.
109	12 Eridani,	7	17 P.	2	54 N.
110	9 Ceti,	44	0 P.	0	47 S.
111		43	3 P.	0	6 S.
112	5 γ Arietis,	5	48 F.	0	17 S.
113	66 4th σ Can.	18	22 F.	1	34 N.
114	18 Leonis min.	13	39 P.	0	35 S.
115		5	47 P.	1	10 N.
116, 117	} 37	11	5 F.	1	1 N.
118	46 Ursæ,	3	41 P.	1	32 S.
119	31 1st *d* Virgin,	6	0 P.	0	55 N.
120	30 *η* Crateri,	9	0 P.	0	17 N.
121	13 *n* Virgin,	18	15 P.	0	19 S.
122	57 μ Eridani,	4	0 P.	0	22 N.
123	60 σ Virg.	52	27 P.	0	30 S.
124		39	57 P.	0	3 S.
125		39	12 P.	1	6 S.

		M.	S.		D.	M.	
126	108,	0	35	P.	1	15	N.
127	110,	1	47	P	0	23	S.
128		3	37	F.	0	30	S.
129	26 χ,	9	46	F.	0	41	S.
130		26	35	F.	0	3	S.
131	14 ι Crateri,	0	29	F.	1	3	N.
132	26 Hydræ,	1	44	F.	0	4	N.
133	49 g Virgin,	16	4	P.	0	18	N.
134		13	27	P.	0	13	N.
135 136	68 ι,	32	2	P.	0	11	N.
137	41 Lyncis,	3	13	F.	0	8	N.
138	102 ε Hydræ,	33	45	F.	1	27	N.
139	11 δ Virgin,	12	1	F.	1	21	S
140		39	55	F.	0	31	S.
141		45	50	F.	1	32	S.
142	37,	6	35	P.	0	0	N.
143	43 δ Virgin,	4	55	F.	2	7	S.
144	109,	25	58	P.	0	54	N.
145 146		25	14	P.	1	27	N.
147	43 Ophiuchi,	8	54	P.	1	17	S.
148	24 α Serpent,	22	26	P.	1	16	S.
149	40 ρ Ophiuchi,	0	14	F.	1	32	N.
150		27	53	F.	0	36	N.
151	71 ι Piscium,	21	41	F.	1	41	N
152	24 ξ Arietis,	16	23	P.	0	20	N.
153	59 2d υ Ceti,	23	16	P.	0	6	S.
154	14 Triang.	1	23	F.	0	59	N.
155	32 Eridani,	7	49	F.	1	1	S.
156	12 p Persei,	1	41	P.	1	10	S.
157	90 υ Piscium,	28	9	F.	0	13	N.
158	48 ν Eridani,	4	32	P.	1	46	S.
159	20 π Cassiop.	8	30	F.	0	33	N.
160	29 γ Virgin,	6	17	P.	2	19	S.
161	6 Comæ,	12	58	F.	0	55	S.
162	29 Comæ,	10	35	F.	0	2	N.
163	20 Sextantis,	8	29	P.	0	22	S.
164	38 Leo min.	2	54	P.	0	36	S.
165	6 Canum,	15	42	P.	0	25	N.
166		1	20	P.	0	23	N.
167	10 n Ursæ,	13	43	F.	1	30	S.
168	34 μ,	4	9	P.	0	6	S.
169	6 Canum,	16	16	P.	0	53	N.
170	20,	28	12	F.	1	6	N.
171	53 2d ν Bootes,	49	57	P.	1	10	N.

		M.	S.		D.	M.	
172	31 Leo min.	25	2	F.	0	3	S.
173		36	19	F.	0	23	N.
174	53 ξ Ursæ,	46	14	F.	0	24	N.
175	13 Canum,	46	3	P.	2	28	N.
176 }		16	33	P	1	26	N.
177 }							
178 }	8,	7	36	F.	0	12	S.
179 }							
180	20,	29	9	F.	3	15	N.
181		40	13	F.	1	11	N.
182	1 Serpentis,	17	22	P.	0	2	S.
183		11	19	P.	0	1	N
184	8 Libræ,	8	21	P.	1	15	S.
185	19 λ Bootes,	11	6	F.	0	1	N.
186		47	14	P.	1	20	N.
187		20	15	P.	1	14	N.
188	38 2d *h*,	13	24	P.	2	44	N.
189	24 *g*,	3	57	F.	0	23	S.
190 }	Canum 6 m,	11	32	F.	1	11	S
191 }							
192	3 Lacertæ,	80	46	P.	2	32	N.
193	54 φ Androm.	1	26	P.	0	54	N.
194	56 Ursæ,	3	19	F.	0	5	N.
195	67,	4	49	F.	0	2	N.
196		7	17	F.	0	38	N.
197 }	8 Canum,	3	32	P.	0	19	N.
198 }							
190	15 Leo min.	32	1	F.	0	24	S.
200	59 2d σ Can.	4	29	P.	0	29	N.
201	63 χ Ursæ,	0	5	F.	0	17	S.
202		0	47	F.	0	4	N.
203	59,	7	42	F.	0	31	N.
204	9,	16	27	P.	2	7	N.
205		22	18	F.	3	1	N.
206	3 Canum,	14	39	P.	1	35	N.
207		14	0	P.	1	32	S.
208		9	9	P.	1	32	N.
209		3	33	P.	1	6	S.
210	60 Ursæ,	46	0	F.	0	9	N.
211	11 Canum,	5	47	F.	1	58	S.
212	60 Ursæ,	50	50	F.	1	58	S.
213	19 λ Bootes,	110	25	P.	1	48	N.
214	17 κ,	8	26	P.	1	56	N.
215.	Neb. II, 757,	3	27	P.	1	14	S.
216	22 Ursæ,	13	52	P.	3	4	S.
217	54 Persei,	9	25	F.	0	46	N.
218	63 Aurigæ,	26	43	F.	0	20	S.

		M.	S.		D.	M.	
219	55 Ursæ,	5	33	F	0	36	N.
220	64 γ Ursæ,	43	59	P.	0	20	S.
221		21	41	P.	0	37	S.
222		20	20	P	0	35	S.
223		6	4	F	2	45	S
224	1 Canum,	9	19	P	3	10	S
225		8	31	P.	0	46	S
226	64 γ Ursæ,	33	32	P.	0	34	S.
227		15	28	P.	2	37	N.
228		5	20	P.	2	24	N.
229		3	46	F.	1	47	N
230	83 Ursæ,	20	24	F	0	27	N.
231		24	34	F.	0	10	N
232		27	7	F	0	16	N.
233	44 Ursæ,	1	14	F.	0	16	S.
234	74 Ursæ,	1	31	F	0	28	S.
235	12 ι Draconis,	66	52	P	2	3	S.
236		59	56	P	2	13	S.
237		54	10	P	0	52	S.
238	69 Ursæ *Hev.*	27	55	P.	0	32	S.
239		28	10	F	0	17	S.
240		28	34	F.	0	17	S.
241	19 Hyd. Crat.	14	43	P.	0	57	S.
242	15 *f* Ursæ,	15	40	P.	0	21	S
243	77 ε Ursæ,	1	47	F.	2	25	N.
244	39 Ursæ,	36	44	F.	0	40	N.
245		39	27	F.	1	58	N.
246	66 Ursæ,	29	19	P.	0	20	N
247		28	13	P.	2	0	N.
248		7	5	P	2	52	N.
249	17 Ursæ,	9	0	P	3	43	N.
250		4	47	P	3	17	N.
251	76 Ursæ,	50	48	P.	2	3	S.
252		41	11	P.	0	34	S.
253		41	46	P.	0	51	S.
254		1	47	P.	1	8	S.
255	69 Ursæ *Hev.*	19	26	F.	1	1	N.
256		21	33	F.	0	13	N.
257	12 Eridani,	16	58	F.	1	58	S.
258	47 λ Persei,	3	41	P.	1	0	N.
259	17 Hydræ Crat.	18	31	F.	0	27	N.
260	23 *h* Ursæ,	1	49	P.	0	34	S.
261	38 of *Connois.*	3	7	F.	1	35	S.
262	1 λ Draconis,	2	6	P.	2	41	S.
263	4 Draconis,	22	48	P.	0	23	S.
264		14	18	P.	1	36	N.

		M.	S.,	D.	M.
265	37 Ursæ,	16	16 P.	1	5 N.
266		13	35 P.	0	11 S.
267	39 Ursæ,	11	21 F.	0	10 S.
268		12	46 F.	0	4 S.
269		18	1 F.	0	29 N.
270		35	36 F.	1	42 N.
271		35	54 F.	0	55 N.
272	Georgium Sidus,	0	53 P.	0	6 N
273	A double star,	5	45 F	0	39 S.
274		10	13 F.	0	24 S.
275	5 Dracon. Hev.	1	32 F.	0	12 N.
276		2	45 F.	0	12 N.
277		0	20 F.	0	20 N.
278		11	5 P.	0	15 S.
279		10	28 P.	1	38 N.
280	16 ζ Ursæ min.	51	53 P	0	3 N.
281	τ Apps Sculps. L C 95,	1	47 P.	0	27 N.
282	208N Camelo of Bode's Cat	153	15 P.	2	43 S.
283		113	40 P	3	4 S.
284		85	18 P.	0	23 S.
285	24 *d* Ursæ,	13	14 F.	1	53 S.
286		30	0 F	1	8 S.
287	1 λ Draconis,	4	37 P.	1	13 N
288	184 Camelo. of Bode's Cat.	11	58 P.	2	34 S.

A table of nebulæ in the southern hemisphere, by La Caille, may be seen in the *Connaissance des Temps* for 1784, p. 270.

X. ON STELLAR NEBULÆ, OR THOSE WITH BURS.

Dr. Herschel supposes that stellar nebulæ may be real clusters of stars, the whole light of which is collected so nearly into one point as to leave but just enough of the light of the cluster visible to produce the appearance of burs. See Nos. 21, 31, 32, 46, 47, 49 of the following catalogue.

XI. ON MILKY NEBULOSITY.

Dr. Herschel considers the phenomena of milky nebulosity as of two kinds, one of which arises from widely extended regions of closely connected clustering stars, like those which form the Milky Way; while the other is real, and possibly at no great

distance. The changes which the milky nebulosity of θ Orion has undergone, both in shape and lustre, seem to indicate that it is not composed of stars. He conceives that this luminous matter may, somehow or other, be formed by means of the light that is continually issuing from the innumerable suns that fill the immensity of space. See Nos 33, 45, 71, 76. See also *Phil. Trans.* 1791, p. 71, and Plate VI, *Sup.* Fig. 12.

XII. OF NEBULOUS STARS.

A nebulous star, which is represented in Plate V, *Sup* Fig 14, is a luminous point, surrounded with an immense visible atmosphere. Dr. Herschel thinks that the central point is a star, from its complete resemblance to a star of equal magnitude. See Nos. 45, 48, 52, 65, 69, 74. See also *Phil. Trans.* 1791, p. 71.

XIII. ON PLANETARY NEBULÆ.

Planetary nebulæ, one of which is represented in Plate V, *Sup.* Fig. 11, is a circular space in the heavens, uniformly luminous, resembling a planetary disc. The light of one of these nebulæ, 15″ in diameter, was hardly equal to that of a star of the 8th or 9th magnitude Hence Dr. Herschel supposes that they can scarcely be bodies like our Sun, as a part of the Sun's disc, 15″ in diameter, would exceed the greatest lustre of the full Moon.

" If, on the other hand," he observes, " we should suppose them to be groups or clusters of stars, at a distance sufficiently great to reduce them to so small an apparent diameter, we shall be at a loss to account for their uniform light, if clusters, or for their circular forms, if mere groups of stars. Perhaps they may be rather allied to nebulous stars; for, should the planetary nebulæ, with lucid centres, be an intermediate step between planetary nebulæ and nebulous stars, the appearances of these different species, when all the individuals of them are fully examined, might throw a considerable light on the subject." See Nos. 1, 11, 18, 27, 51, 53, 60, 64, 70.

XIV. ON PLANETARY NEBULÆ, WITH CENTRES.

This class differs only from the last in having a bright central point, as represented in Plate V, *Sup.* Fig. 14. Dr. Herschel remarks, that if a gradual condensation of the nebulosity

about a nebulous star could take place, the star No. 73 in the following catalogue would be one of them, in an advanced state of compression. See No. 37.

Catalogue of Planetary Nebulæ, Stars with Burs, Milky Chevelures, Short Rays, Remarkable Shapes, &c. relating to the five preceding Articles.

Number.	Stars by which the Nebulæ may be found.	Difference of Right Ascension between the Nebulæ and the Star.		Difference in Declination.	
		M.	S.	D.	M.
1	13 ν Aquarii,	5	24 P.	0	2 N.
2	13 Monocer.	6	4 F.	1	27 N.
3	15 Monocer.	8	18 P.	0	15 N.
4	69 Leonis,	10	3 F.	1	3 S.
5	29 γ Virginis,	9	0 P.	1	33 N.
6	59 c Leonis,	9	0 P.	0	18 S.
7	51 m Leonis,	17	0 F.	0	39 S.
8	34 Virginis,	10	12 P.	0	51 S.
9	51 m Leonis,	21	15 P.	1	48 S.
10	51 e Ophiuchi,	1	42 P.	0	14 N.
11	3 p Sagittæ,	22	0 F.	1	47 N.
12	39 h Signi,	8	6 P.	1	35 S
13	21 Vulpec.	2	6 F.	1	51 N.
14	27 Aquilæ,	6	6 P.	1	45 S.
15	21 α Androm.	2	6 F.	1	21 S.
16	16 η Sagittar.	17	12 F.	0	1 N.
17	81 Ceti,	36	30 F.	0	36 N.
18	14 Androm.	6	11 P	3	16 N.
19	5 Monocer.	7	6 P.	0	10 S.
20	———	3	42 P.	0	3 N.
21	12 Leporis,	8	48 P.	0	24 N.
22	7 ξ Navis,	3	10 F.	1	28 S.
23	75 Ceti,	4	40 P.	0	6 S.
24	50 ζ Orionis,	0	57 F.	0	17 S.
25	19 Navis,	67	0 P.	1	15 N.
26	34 γ Eridani,	16	16 F.	0	49 N.
27	6 3 b Crateris,	98	39 P.	1	25 N.
28	31 Crateris,	1	0 F.	0	47 N.
29	4 ν Crateris,	3	36 F.	0	16 N.
30	14 Canum,	6	48 P.	0	55
31	50 Aquarii,	7	55 F.	0	37
32	62 b Eridani,	0	35 F.	0	21 N.
33	49 d Orion,	2	33 P.	0	28 N.
34	40 2d φ Orion,	5	41 F.	0	12 S.

		M.	S.		D.	M.	
35	9 Hydræ,	8	19	P.	0	14	S.
36	60 Orionis,	11	38	P.	0	20	S.
37	28 ω Draco,	20	33	F.	2	12	S.
38	55 Orionis,	18	3	F.	1	17	N.
39	2 Navis,	3	32	P.	0	5	S.
40	68 ι Virginis,	30	45	P.	0	18	S.
41	14 Sagittarii,	11	58	P.	1	15	S.
42	51 Ceti,	7	26	F.	0	27	N.
43	26 β Persei,	2	48	P.	1	54	N.
44	5 Monocero.	7	16	P.	0	2	S.
45	55 δ Gemin.	9	6	F.	1	1	S.
46	99 ι Virginis,	4	38	P	0	57	N.
47	44 k ———	1	48	F.	0	46	S.
48	19 Leo min.	6	32	F.	0	17	S.
49	102 1st υ Vir.	6	9	P.	0	52	S.
50	77 κ Hercul.	40	13	P.	0	28	S.
51	61 g Sagitt.	13	56	P.	1	23	N.
52	4 d Cassiopeia,	4	0	P.	1	6	S.
53	10 Camelopard,	55	42	P.	0	11	N.
54	67 Ursæ,	7	32	F.	0	30	S.
55	34 Lyncis,	28	4	P.	0	2	N.
56	56 Ursæ,	25	11	F.	0	56	N.
57	35 σ Hercul.	34	27	F.	0	18	S.
58	24 Cephei,	116	28	F.	0	2	N.
59	55 Ursæ,	4	59	F.	0	23	N.
60	36 Ursæ,	8	37	F.	2	28	S.
61	64 γ Ursæ,	3	56	F.	0	19	S.
62	———	2	27	F.	1	25	N.
63	69 Ursæ Hev.	1	24	F.	1	33	S.
64	6 Navis,	7	41	P.	1	2	S.
65	28 Monocero.	51	49	P.	0	26	N.
66	17 Ursæ,	16	29	P.	3	6	S.
67	66 Ursæ,	0	39	P.	1	55	N.
68	45 Lyncis,	4	15	P.	1	44	N.
69	{ 26 Aurigæ, or	88	24	P.	0	11	S.
	{ 31 Hevel.	24	59	F.	1	26	S
70	6 Draconis,	50	27	F	0	27	N.
71	37 ξ Bootes,	16	5	F.	0	44	S.
72	34 Cygni,	5	10	P.	0	23	N.
73	16 c. Cygni,	2	51	F.	0	1	S.
74	7 Cephei,	24	57	P.	1	22	N.
75	7 Cephei,	14	40	F.	0	46	S.
76	3 η Cephei,	10	31	P.	1	36	S.
77	16 Eridani,	4	56	F.	0	14	N.
78	{ 8 Ursæ min. of Bode's Cat. }	25	0	P.	0	12	N.

Remarks on the Nebulæ in the preceding Catalogue, according to Dr. Herschel's Observations.

No. 1. A very bright planetary disc, nearly round, but not well defined.

2. Considerably bright. Represented in Plate V, *Sup.* Fig. 8.

3. Like a star with an electrical brush. See Plate V, Fig. 10.

4. Extremely faint, like a star with a very faint brush.

5. A star with a milky ray, 15′ or 20′ long. See Fig. 21.

6. A central bright point, with a milky chevelure.

8 and 9. A close double nebula. The chevelures run into each other.

10. Star with a faint brush N. F. and two small stars visible in it.

11. Defined planetary disc, 30″ or 40″ diameter.

12. 3′ or 4′ diameter, like a brush to a star N. P.

13. 1′ diameter, round, and well defined.

14. 1′ diameter, and resolvable into stars.

15. A faint star, with a small chevelure and two burs.

16. Pretty bright, round, pretty well defined, and 45″ in diameter.

17. A small star, with a faint nebulous brush, about 2′ long.

18. A round, bright, well defined planetary disc, 15″ in diameter.

19. A star of the 9th magnitude, with an elliptical milky chevelure.

20. A star of the 12th magnitude, like the preceding.

21. Stellar, with a very bright nucleus, and a faint chevelure, not quite central.

22. 9′ diameter, round, and easily resolved into stars.

23. A very bright nucleus, with a chevelure, about 4′ diameter.

24. A bright star, with a chevelure, 5′ long, and 4′ broad.

25. A considerable star, with a very faint, small, and irregular milky chevelure.

26. A bright, round, ill defined planetary disc. It is resolvable on the borders, and is probably a very compressed cluster at an immense distance.

27. A beautiful, brilliant planetary disc, ill defined, but uniformly bright, 40″ diameter.

28. A pretty bright and large opening, with a branch, or two nebulæ, very faintly joined.

29. A very small star, with a very faint brush preceding.

30. Two stars, 3′ distant, connected with a faint narrow nebulosity.

31. Stellar, with a pretty large chevelure.

32. Small and bright in the middle, like a star affected with irregular burs.

33 A star with milky chevelure, or a very bright nucleus, with milky nebulosity.

34. An ill defined planetary nebula.

35 A small star, with a brush S. P.

36. A star not quite in the centre of a milky chevelure.

37. A very bright planetary nebula, about 35″ diameter. Its edge is ill defined. After long attention, a very bright, well defined, round centre becomes visible.

38. A considerable star, with a faint milky chevelure.

39. A bright round nebula, within a cluster. It is 2′ diameter, but is unconnected with the cluster.

40. A pretty bright star, with a seeming brush north preceding it.

41. A double star, with extensive nebulosity of different intensity. About the double star is a black opening, resembling the nebula in Orion.

42. A star of the 8th or 9th magnitude, with faint branches, each 1′ long.

43. A pretty bright star, with two faint branches.

44. A star in a milky chevelure.

45. A star of the 9th magnitude, with a pretty bright milky nebulosity, equally dispersed all around; a very remarkable phenomenon.

46. A small, but pretty bright stellar nebula, like a star with burs.

47. A pretty bright stellar nebula, resembling a star with a bur all around.

48. A faint star, with a faint nebulosity, extending 1′ S. P. and N. F.

49. A pretty bright stellar nebula, with a small bur all around.

50. Bright and round 4′ diameter, equally bright, with a margin resolvable into stars.

51. A small, bright, and round beautiful planetary nebula, 10″ or 15″ diameter. It is considerably hazy in the edges, but of an uniform light.

52. A star of the 9th magnitude, with a faint and small nebulosity about it.

53. A pretty bright planetary nebula, near 1′ diameter, roundish, of uniform light, and pretty well defined.

54. A considerably bright small nucleus, with faint chevelure.

55. Pretty bright and round. Its light is pretty uniform, but ill defined, and a little fainter at the edges, 1′ diameter.

56. A considerably bright nucleus, in the middle of an extensive chevelure, 5′ in diameter.

57. A small star in a faint nebulosity.

58. A star of the 9th magnitude, surrounded with faint milky nebulosity. The star is either double or not round. Less than 1′ diameter

59. A considerably well defined nucleus, with a very faint chevelure.

60. A bright round planetary nebula, but indistinct on the edges, so as to make it a step between planetary nebulæ and those which are described as very suddenly much brighter in the middle.

61. Bright, with a bright round nucleus, and very faint branches, extending about 30° N. P. and S. F. or 8′ long, and 5 broad.

62. Considerably bright, and quite round. A large space in the middle, equally bright, but less bright at the margin.

63. 4′ in diameter, round, and much brighter in the middle.

64. A beautiful planetary nebula, of a considerable degree of brightness, about 12″ or 15″ in diameter, not well defined.

65. A star of the 9th or 10th magnitude, affected with a faint nebulosity all around.

66. A small star, with a pretty bright fan-shaped nebula. The star is on the preceding side of the chevelure, and seems connected with it.

67. Between 2′ and 3′ in diameter, round and bright. The greater part of it is equally bright, then fading away suddenly.

68. Bright and round, with a bright nucleus in the middle, and a faint chevelure joined to it.

69. A small star of the 8th magnitude, with a faint luminous atmosphere, of a circular form, about 3′ in diameter. The star is exactly in the centre, and the atmosphere so diluted, faint, and equal throughout, that it cannot be supposed to consist of stars, and the star and the atmosphere are evidently connected.

70. Round, considerably bright, and 30″ in diameter. It resembles an ill defined planetary nebula.

71. A star of the 7.6 magnitude, enveloped in an extensive milky nebulosity.

72. A double star of the 8th magnitude, with a faint milky ray S. P. joined to it, about 8′ long, and 1′ 30″ broad.

73. A bright point, a little extended, like two points close to one another. It is as bright as a star of the 8.9 magnitude, surrounded by a very bright milky nebulosity, suddenly terminated, having the appearance of a planetary nebula, with a lucid centre. The border is not well defined. It is perfectly round, and about 1′ 30″ in diameter. This is a beautiful phenomenon, and is of a middle species between the planetary nebulæ and nebulous stars.

74. A star of the 7th magnitnde, with a nebulosity extending a degree all around.

75. Three stars of the 9th magnitude, involved in nebulosity, about 1′ 30″ in diameter.

76. Faint, with a bright nucleus in the middle, seeming to consist of stars. The nebulosity, of 6′ or 7′ is of the milky kind.

77. A star of the 9th or 10th magnitude, with a nebulous ray about 1′ 30″ long on the S. P. side.

78. Considerably bright and round, approaching to a planetary nebula, with a strong hazy border, 1′ 30″ in diameter.

CHAP. XII.

ON PRACTICAL ASTRONOMY, WITH AN ACCOUNT OF THE INSTRUMENTS USED IN OBSERVATORIES.

Practical Astronomy is that branch of the science which treats of the description and use of Astronomical Instruments, the object of which is, to determine the magnitudes of the heavenly bodies, and their position in space.

The principal instruments which are used in observatories are the following:—

1. Micrometers.
2. Transit Instruments.
3. Quadrants.
4. Circular Instruments.
5. Equatorial Instruments.

Before we proceed to describe these instruments, we shall endeavour to explain the principle and construction of the *Vernier Scale*, a simple contrivance, which forms a necessary part of every graduated instrument.

The *Vernier Scale* is represented in Plate VIII, *Sup.* Fig. 2, where A B is a portion of the limb of an instrument, suppose *one degree*, which is subdivided into *twelve* parts, each of which is the 12th part of a degree, or 5 minutes. In order to subdivide each of these spaces into *half minutes*, a scale E F is fixed to the telescope. The index or *zero* at the commencement of this scale is shewn at I, and as it points somewhere between 50 and 55 minutes on the limb A B, we have to determine the exact number of minutes and half minutes to which it points. As the number of half minutes in any of the spaces on the limb is *ten*, add *one* to this number, which makes *eleven*, and take eleven divisions, viz. A x on the limb in a pair of compasses; set this space from I to y on the scale, and divide into *ten* equal parts, two of which will correspond to one minute, and place the minutes at 1, 2, 3, 4, 5. Then, looking at the scale and the limb at the same time, observe which division on the scale corresponds most accurately with one on the limb, which in the present case will be found to be the one marked $3\frac{1}{2}$ minutes. Hence the index 0 points to a spot $3\frac{1}{2}$ minutes beyond 50 minutes, that is, to $53\frac{1}{2}$ minutes, or 53′ 30″.

Since each division on the limb is *one eleventh* of the space A x = 55 minutes, and since each division on the scale is *one tenth* of the same space, it will be $5\frac{1}{2}$ minutes; and consequently each division on the Vernier scale will be $\frac{1}{2}$ a minute less than each division on the limb. But since the division line m of the scale is coincident with the division line a on the limb, the line n will extend beyond b *one* half minute, o beyond c *two* half minutes, p beyond d *three* half minutes, q beyond e *four* half minutes, r beyond f *five* half minutes, s beyond g *six* half minutes, and I beyond h *seven* half minutes, that is, the index I will point to a spot seven half minutes, or $3\frac{1}{2}'$ beyond the 50th minute at h.

If we wished to subdivide the space of five minutes into 60 parts or every five seconds, then it would have been necessary to take 61 divisions on the limb, and divide it into 60 parts for the Vernier scale.

I. DESCRIPTION OF MICROMETERS.

A micrometer is an instrument which is attached to a telescope, in order to measure small spaces in the heavens, such as the diameters of the Sun, Moon, and planets, &c. The micrometers which are most commonly used, are the *wire micrometer* and the *divided object-glass micrometer.*

1. *Wire Micrometer.*

This instrument, as fitted up in the eye-piece of a telescope, is shewn in Plate VIII, *Sup.* Fig. 3, where S S E is the eye-piece which screws upon the telescope at S S, E the place of the eye, and M N the micrometer placed in the focus of the eye-glass at E. A section of the micrometer through M N is shewn in Fig. 4, where F F F F is a box or frame of brass, and M P N a steel wire having the part M P (which passes through a hole in the side of the box) formed into a fine screw with 200 or 300 threads in an inch. The other end Q N is guided through a little tube F N. This wire either forms part of the steel frame P Q R T, or is firmly fixed to it. To the point W of this frame is fastened a chain W′ W, which coils round the box W X, in which there is a steel spring. A graduated head A B divided into 100 parts, and attached to the milled nut C, screws upon the fine screw M P, and bears against the index I I, attached to the box F F. If we now turn the milled head C so as to screw it towards P, the steel wire M P N and its frame P Q R T will move towards A B, uncoiling the chain W′ W from the barrel or box X; but if we screw in the opposite direction, the spring in the box X pulling against the frame R Q, by the chain W′ W, will cause it to move towards D N. A slender silver wire, or the fibre of a spider's web, being now stretched across the lower side of the frame P Q R T at *o p*, may be moved across the aperture of the telescope, by turning the milled head C. Another wire *m n* parallel to *o p* is fixed upon the brass box, and a third wire *r s* at right angles to it. In general, however, it is preferable to fix these two last wires to the upper side of another frame, *p q r t*, Fig. 5, which lies below the frame P Q R T, and which is capable of being moved by means of the screw D *d*. These frames are so constructed that the fibres *m n*, *o p* can pass each other without touching, and that when the one is behind the other, they appear as one fibre. Let us now suppose that the instrument is put together as in Fig. 3, and that we wish to measure

Catalogue of Two Hundred and Eighty-eight of the First Class, or Class of Bright Nebulæ, according to the Observations of Dr. Herschel.

First Class.					
Number.	Stars by which the Nebulæ may be found.	Difference of Right Ascension in Time between the Nebulæ and the Star.		Difference in Declination.	
		M.	S.	D.	M
1	82 δ Ceti,	2	17 F.	0	8 N.
2	3 Leonis,	18	7 P.	1	12 S.
3	34 Sextantis,	28	55 P.	0	13 S.
4		28	27 P.	0	10 S.
5	81 Leonis,	2	42 P.	0	7 N.
6	64 Virginis,	33	56 F.	0	1 S.
7	49 Leonis,	126	45 F.	0	40 S.
8	32 2 *l* Virgin,	2	50 F.	0	48 N.
9	10 *r* Virginis,	3	12 F.	0	35 S.
10		33	37 F.	0	4 N.
11	5 Comæ Be.	1	30 P.	2	11 S.
12	6 Comæ,	9	12 F.	0	9 S.
13	69 Leonis,	7	57 P.	0	2 N.
14	29 γ Virginis,	0	43 F.	1	23 N.
15		3	23 F.	0	58 N.
16		10	34 F.	0	13 N.
17	46 *i* Leo,	15	50 F.	1	32 S.
18		16	18 F.	1	29 S.
19	11 Comæ,	10	30 P.	0	46 N.
20	73 *n* Leonis,	8	52 F.	1	57 S.
21		25	31 F.	1	49 S.
22	34 Virginis,	22	24 P.	0	17 S.
23		18	24 P.	0	19 S.
24	30 ρ Virginis,	1	42 P.	0	5 S.
25	34 Virginis,	4	45 F.	0	40 S.
26	52 K Leonis,	3	45 P.	2	9 S.
27	46 *i* Leonis,	18	47 F.	0	43 S.
28	34 Virginis,	19	36 P.	1	8 N.
29	73 *n* Leonis,	1	9 P.	0	30 S.
30	31 1 *d* Virginis,	17	41 P.	0	32 N.
31	31 1 *d* Virginis,	8	0 P.	0	37 N.
32		5	11 P.	0	28 N.
33	9 ι Virginis,	3	12 F.	1	39 N.

		M.	S.	D.	M.
34	59 *e* Virginis,	20	42 F.	0	34 S.
35	34 Virginis,	31	42 P.	1	5 N.
36 37	*	11	24 P.	0	20 N.
38	32 2 *d* Virgin,	11	36 P.	0	0 N.
39	51 *θ* Virginis,	21	36 P.	0	14 S.
40		5	48 P.	0	2 N.
41	28 Virginis,	9	24 F.	1	2 N.
42	26 *χ* Virginis,	30	27 F.	0	8 N.
43	49 *g* Virginis,	28	6 P.	0	51 S.
44	51 *e* Ophiuchi,	7	18 F.	0	0 N.
45	43 Ophiuchi,	6	36 P.	0	4 N.
46		0	54 F.	1	46 N.
47	1 *m* Aquilæ,	17	48 F.	0	33 S.
48	43 *d* Sagittarius,	114	6 P.	1	44 N.
49	10 *γ* Sagittarius,	2	18 P.	0	23 N.
50	19 *δ* Sagittarius,	3	0 F.	0	33 S.
51	22 *λ* Sagittarius,	3	12 F.	0	13 S.
52	17 Delphini,	6	0 F.	2	24 N.
53	66 *υ* Cygni,	78	6 F.	0	51 S.
54	35 *ν* Andromeda,	18	36 F.	1	26 S.
55	66 Pegasi,	17	59 P.	0	2 N.
56 57	4 *λ* Leonis,	0	46 F.	1	29 S.
58	19 Eridani,	5	9 F.	1	22 S.
59	15 *ι* Navis,	64	18 F.	0	21 N.
60	19 Eridani,	6	51 P.	0	16 N.
61	6 Sextantis,	8	42 P.	0	31 N.
62	55 *ζ* Ceti,	0	25 P.	0	37 N.
63	80 Ceti,	5	12 F.	0	25 S.
64	8 1 *ρ* Eridani,	15	9 P.	0	2 N.
65	31 Crateris,	23	30 F.	0	52 N.
66	12 Hydræ,	25	2 F.	1	7 S.
67	8 *η* Corvi,	37	17 P.	2	10 N.
68	53 Virginis,	12	40 P.	1	4 N.
69		11	4 P.	1	34 N.
70	106 Virginis,	1	2 F.	0	54 N.
71	19 *δ* Libræ,	0	3 P.	1	4 N.
72	23 Leonis min.	13	7 F.	0	[illegible] N.
73	13 Can. vena,	50	17 P.	0	22 S.
74	13 Can. vena,	43	5 P.	1	11 S.
75		40	35 P.	1	9 S.
76		38	3 P.	0	52 S.
77		34	15 P.	0	23 N.
78	27 Ursæ	7	46 F.	0	4 N.
79		33	52 F.	1	17 N.

with it the sun's diameter, as seen in the field of view *r o m s n p*, Fig. 4. Having turned round the whole micrometer till the lower limb of the Sun moves along the fixed wire *m n*, turn the nut C so as to bring the other wire *o p* in contact with the upper limb of the Sun, and so that the Sun in its motion through the field of the telescope may be exactly comprehended between the wires. When this is done, the distance of the wires *m n*, *o p* becomes a measure of the Sun's diameter. Let the nut C be now turned so as to bring the wire *o p* exactly into coincidence with *m n*, and let it be carefully observed by means of the scale upon F E, Fig. 3, and the divisions on A B, how many turns and hundredths of a turn of the nut C are necessary to bring the wires into coincidence. Suppose the number to be 108.40, or 108 turns and 40 hundredths of a turn; then before we can convert this measure into minutes and seconds, we must ascertain experimentally the angular value of a given number of turns, suppose 100, which may be easily done by separating the wires 100 turns, and observing how much of an object placed at a given distance is comprehended between the wires. Let the interval comprehended by the wires be 40 feet, at the distance of 4584 feet: then it will be found by experiment that the angle corresponding to this is 30′; and hence we have the following analogy—

$$\text{As } \overset{\text{Turns.}}{100} : 30' :: \overset{\text{Turns.}}{108.40} : 32'\ 31''.2.$$

the diameter of the Sun required.

The scale of the micrometer may also be determined by observing the time in which an equatorial star passes through any given distance of the wires, and converting this into degrees by the Table in Vol. I, p. 108.

2. *Divided Object-Glass Micrometer.*

The divided object-glass micrometer is principally useful for measuring the diameter of lucid discs, such as those of the Sun and Moon, though it may be employed for all micrometrical purposes. It consists of two semi-lenses, A, B, Plate VIII, *Sup.* Fig. 6 (formed by bisecting a lens), each of which gives a separate image of the lucid disc. When the semi-lenses are much separated, they give two detached images, as at P; when their separation is less and of a certain amount, the two images are in accurate contact, as at N; when they are still closer, the images overlap one another, as at M; and when the centres of A and B coincide, the two images coincide also, and form only one image,

If the object-glass of a telescope is thus bisected, and if one of the lenses is moved by means of a screw, in the same manner as the frame is moved in Fig. 4, we may measure the separation of the lenses by means of a scale subdivided by a circular head; and the value of any number of turns of the screw may be ascertained in the same manner as in the wire micrometer. In order to use the instrument, we have only to direct it to the Sun, for example, and separate the semi-lenses till the two images of it are in contact. The separation of the lenses will then furnish a measure of the Sun's diameter.

The simplest form of the divided object-glass micrometer is that which I have described in my *Treatise on New Philosophical Instruments*, p. 31. The semi-lenses are fixed at an invariable distance, and are moved in tubes between the object-glass of a telescope and its principal focus. The motion towards the focus closes the images, and the motion towards the object-glass shuts them; and on a scale engraven upon tubes, and formed experimentally, is pointed out the precise angle subtended by the object, when its two images are in contact.

II. ON THE TRANSIT INSTRUMENT.

A transit instrument is a telescope, moveable in the plane of the meridian upon a horizontal axis, for the purpose of observing the precise instant when any celestial object passes the meridian. One of Mr. Troughton's portable transit instruments is represented in Plate VIII, *Sup.* Fig. 7, where P P is an achromatic telescope, firmly fixed by the middle to a doubly conical and horizontal axis H H, the pivots of which rest on angular bearings called Y's, at the top of the standards B, B, rendered steady by oblique braces D, D, fastened to the central part of the circle A, A. The axis H H has two adjustments, one for making it exactly level, and the other for placing the telescope in the meridian. A graduated circle L is fixed to the extremity of the pivot which extends beyond one of the Y's, and the two radii that carry the verniers *a*, *a*, are fitted to the extremity of the pivot in such a way as to turn round independent of the axis. The double verniers have a small level attached to them, and a third arm *b*, which is connected with the standard B by means of a screw *s*. If the verniers are

placed, by means of the level, in a true horizontal position, when the axis of the telescope is horizontal, and the arm *b* screwed by the screw *s* to the standard B, the verniers will always read off the inclination of the telescope, and will enable the observer to point it to any star, by means of its meridian altitude. The whole instrument rests on three foot-screws entered into the circle A A. The telescope has a diagonal eye-piece for observing stars near the zenith, and in the field of view there are several parallel vertical wires crossed at right angles with a horizontal one.

In order to fix the transit instrument exactly in the meridian, the clock should be previously regulated to sidereal time, by means of corresponding or equal altitudes of the Sun or a star, taken before and after they pass the meridian, by small quadrants or circles, or by a good sextant. The axis H H of the transit is then to be placed horizontal by means of a spirit level, which accompanies the instrument, and the greatest care must be taken that the axis of vision describes in the heavens a great circle of the sphere.

The reader will find a very minute account of the method of making all these verifications in the *Edinburgh Encyclopædia*, Art *Astronomy*, vol. ii, p. 730, 731, 732.

III. ON THE QUADRANT.

A quadrant is the fourth part of a circle, having its limb divided into 90 degrees, for the purpose of measuring the altitudes of bodies above the horizon. The principle of the quadrant having been already clearly explained in Vol. I, p. 86, *Note*, we shall content ourselves with giving a description of the *pillar quadrant*, as constructed by Bird. This instrument is represented in Plate VIII, *Sup.* Fig. 8, and consists of a quadrant E F, H G L, mounted on a pillar B, which is supported by a tripod A A, resting on three foot-screws. The quadrant, the pillar and the horizontal circle all revolve round a vertical axis. A telescope H is placed on the horizontal radius, and is directed to a meridian mark, previously made on some distant object for placing the plane of the instrument in the meridian, and also for setting the zero or beginning of the scale truly horizontal. This is sometimes done by a level, instead of a telescope, and some-

times by a plumb-line G, suspended from near the centre, and brought to bisect a fine dot made on the limb, where a microscope *a* is placed to examine the bisection. The weight or plummet at the end of the plumb-line is suspended in the cistern of water *b*, which keeps it from being agitated by the air. A similar dot is made for the upper end of the plumb-line upon a piece of brass, adjustable by a screw *d*, in order that the line may be exactly at right angles to the telescope, when it is placed at 0°.

The central part of the frame of the quadrant is screwed to a piece of brass *e* by three screws, and this piece is again screwed by three other screws to the top of the pillar B. By means of the three first screws, the plane of the quadrant can be placed exactly parallel to the vertical axis, and by the other screws the telescope H can be placed exactly perpendicular to it. The nut of the delicate screw L is attached by an universal joint to the end of the telescope F. The collar for the other end is attached by a similar joint to a clamp *r*, which can be fastened to any part of the limb. A similar clamp-screw and slow motion is seen at *n* for the lower circle.

In using this instrument, the axis of the telescope H is adjusted to a horizontal line, and the plane of the quadrant to a vertical line, by the means already mentioned. The screw of the clamp L is then loosened, and the telescope directed to the star whose altitude is required. The clamp-screw being fixed, the observer looks through the telescope, and with the nut of the screw L he brings the telescope into a position where the star is bisected by the intersection of the wires in the field of the telescope. The divisions are then to be read off upon the vernier, and the altitude of the star will be obtained.

By means of the horizontal circle D, all angles in the plane of the horizon may be accurately measured.

A full account of the method of adjusting and using the astronomical quadrant will be found in the *Edinburgh Encyclopædia*, Art. *Astronomy*, Vol II, p. 726.

IV. ON ASTRONOMICAL CIRCLES.

An astronomical circle is nothing more than a complete circle, substituted in place of the quadrant, and differs in no respect

from this last instrument, except in the superior accuracy with which it enables the practical astronomer to make his observations. One of these instruments, as constructed by Mr. Troughton, for Major-general Sir Thomas Brisbane, is represented in Plate VIII, *Sup*. Fig. 9. The large vertical or declination circle C C, is composed of two complete circles, strengthened by an edge bar on their inside, and firmly united at their extreme borders by a number of short braces or bars which stand perpendicular between them, and which keep them at such a distance as to admit the achromatic telescope T T. This double circle is supported by 16 conical bars, firmly united along with the telescope to a horizontal axis. The exterior limb of each circle is divided into degrees, and parts of a degree, sometimes upon the brass itself, and sometimes upon rings either of silver or an alloy of platina inlaid in the brass, and these divisions are subdivided into seconds by means of the micrometer microscopes *m*, *m*, which read off the angle on the opposite sides of each circle. The cross wires in each microscope may be moved over the limb till they coincide with the nearest division of the limb by means of the micrometer screws *c*, *c*, and the space moved through is ascertained by the divisions on the graduated head above *e*, assisted by a scale within the microscope. The microscopes are supported by two arms proceeding from a small circle concentric with the horizontal axis, and fixed to the vertical columns. This circle is the centre upon which they can turn round nearly a quadrant, for the purpose of employing a new portion of the divisions of the circle, when it is reckoned prudent to repeat any delicate observations upon different parts of the limb. A small capstan head-screw seen at the top of the front column, serves to clamp or fix the microscopes in any position where the observer wishes them to be placed. At *h* is represented a level for placing the axis in a true horizontal line, and at *k* is fixed another level parallel to the telescope, for bringing the zero of the divisions to a horizontal position. The horizontal axis to which the vertical circle and the telescope are fixed, is equal in length to the distance between the vertical pillars, and its pivots are supported by semicircular bearings, placed at the top of each pillar. These two vertical pillars are firmly united at their bases to a cross bar *f*. To this cross bar is also fixed a vertical axis about three feet long, the lower end of which terminating in an obtuse point, rests in

brass conical socket firmly fastened at the bottom of the hollow in the stone pedestal D, which receives the vertical axis. This socket supports the whole weight of the moveable part of the instrument. The upper part of the vertical axis is supported between two pieces of brass, one of which is seen at *c*, screwed to the ring *i*, and containing a right angle or V. At each side of the ring, opposite to the points of contact, is placed a tube containing a helical spring, which, by a constant pressure on the axis, keeps it against its bearings, and permits it to turn in these four points of contact with an easy and steady motion. The two bearings are fixed upon two rings capable of a lateral adjustment; the lower one by the screw *d* to incline the axis to the east or west, while the screw *b* gives the upper ring *i* a motion in the plane of the meridian. By this means the axis may be adjusted to a perpendicular position as exactly as by the usual method of the tripod with feet screws. These rings are attached to the centre piece *s*, which is firmly connected with the upper surface of the stone by six conical tubes A, A, A, A, &c. and brass standards at every angle of the hexagonal pedestal. Below this frame lies the azimuth circle E E, consisting of a circular limb, strengthened by 10 hollow cones firmly united with the vertical axis, and consequently turning freely along with it. The azimuth circle E E is divided and read off in the same manner as the vertical circle. The arms of the microscopes B B project from the ring *i*, and the microscopes themselves are adjustable by screws, to bring them to zero, and to the diameter of the circle. A little above the ring *i* is fixed an arm L, which embraces and holds fast the vertical axis with the aid of a clamp screw. The arm L is connected at the extremity with one of the cones A, by means of the screw *a*; so that by turning this screw, a slow motion is communicated to the vertical axis and the azimuth circle. A slow motion of a similar kind is given to the vertical circle by the clamp and slow motion screw at *v*. The apparatus for this purpose is supported by a piece of hammered brass, screwed to one of the pillars, and made thin and pliable in the direction of the horizontal axis, so as to apply itself to the limb of the circle, without deranging its position, while at the same time it is sufficiently firm in the direction of the motion which it is intended to prevent.

In order to place the instrument in a true vertical position, a plumb-line, made of fine silver wire, is suspended from a

small hook at the top of the vertical tube *n*, connected by braces with one of the large pillars. The plumb-line passes through an angle, in which it rests, and by means of a screw may be brought into the axis of the tube. The plummet at the lower end of the line is immersed in a cistern of water *t*, in order to check its oscillations, and is supported on a shelf proceeding from one of the pillars. At the lower end of the tube *n* are fixed two microscopes *o*, *p*, at right angles to one another, and opposite to each is placed a small tube, containing a lucid point. The plumb-line is then brought into such a position by the screws *d*, *b*, and by altering the suspension of the plumb-line itself, that the image of the luminous point, like the disc of a planet, is formed on the plumb-line, and accurately bisected by it. The vertical axis is then turned round, and the plumb-line examined in some other position. If it still bisects the luminous point, the instrument is truly vertical; but if it does not, one-half of the deviation must be corrected by the screws *d*, *b*, and the other half by altering the suspension of the line, till the bisection of the circular image is perfect in every position of the instrument.

A *Mural Circle*, or a *Mural Quadrant*, is the name given to these instruments when they are fixed in the plane of the meridian, and upon a wall of stone. When furnished with a good telescope, they unite the properties both of a circle and a transit instrument.

General directions for using Circular instruments will be found in the *Edinburgh Encyclopædia*, Art. *Astronomy*, vol. ii, p 728

Tabular View of the Solar System.

Names of the Planets.	Mean diameters in English miles.	Mean distances from the Sun, in round numbers of miles.	The correct mean distances, that of the Earth being 100000.	Mean apparent diameters, as seen from the Earth.	Mean diameters, as seen from the Sun.	Densities, that of water being 1.	Proportional quantities of matter.	Diurnal rotations round their own axis.	Inclinations of axes to orbits.	Inclinations of orbits to the ecliptic in 1780.
The Sun	883246			32′ 1″.5		$1\frac{2}{13}$	333928	25d 14h 8′ 0″	82° 44′ 0″	
Mercury	3224	37,000,000	38710	10	16″	$9\frac{1}{8}$	0.1654	14 24 5 28	- - -	7° 0′ 0″
Venus	7687	68,000,000	72333	58	30	$5\frac{11}{15}$	0.8899	0 23 21 8	- - -	3 23 35
The Earth	7911,73	95,000,000	100000		17 .2		1	1 0 0 0	66 32 0	0 0 0
The Moon	2180	95,000,000	100000	31 8	4 .6	$4\frac{1}{2}$	0.025	29 17 44 3	88 17 0	5 9 3 at a mean.
Mars	4189	144,000,000	152369	27	10	$3\frac{2}{7}$	0.0875	0 24 39 22	59 22 0	1 51 0
Ceres	163 } 1024 }	263,000,000	276500	{ 1 } { 6 .4 }	- -	2	- -	- - - -	- - -	10 37 0 in 1804.
Pallas	80 } 2099 }	265,000,000	279100	{ 0 .5 } { 6 .5 }	- -	2	- -	- - - -	- - -	34 50 40 in 1804.
Juno	1425	252,000,000	265700	3	- -	- -	- -	27 hours probably.	- - -	21 0 13 4 in 1804.
Vesta	238	225,000,000	237300	0 .5	- -	- -	- -	- - - -	- - -	7 8 46 in 1809.
Jupiter	89170	490,000,000	520279	39	37	$1\frac{1}{24}$	312.1	0 9 55 37	90 nearly.	1 18 56 in 1780.
Saturn	79042	900,000,000	954072	18	16	$0\frac{13}{32}$	97.76	0 10 16 2	60 probably.	2 29 50 in 1780.
Georgium Sidus	35112	1,800,000,000	1908352	3 54	4	$0\frac{22}{100}$	16.84	- - - -	- - -	0 46 20 in 1780.

TABULAR View of the Solar System

Names of the Planets.	Tropical revolutions.	Sidereal revolutions	Place of Aphelion in January 1800	Motion of the Aphelion in 100 years.	Longitude of ascending node in 1800	Motion of nodes in 100 years.	Eccentricities the mean distances being 100000	Greatest equation of centre
The Sun								
Mercury	87d 23h 14′ 32″.7	87d 23h 15′ 34″ 6	8s 14° 20′ 50″	1° 33′ 45″	1s 15° 20′ 43′	1° 12′ 10″	7955 4	23h 40′ 0″
Venus	224 16 41 27 .5	224 16 49 10 6	10 7 59 1	1 21 0	2 14 26 18	0 51 40	498	0 47 20
The Earth	365 5 48 49	365 6 9 12	9 8 40 12	0 19 35			1681.395	1 55 30
The Moon								
Mars	686 22 18 27 .4	686 23 30 35 .6	5 2 24 4	1 51 40	1 17 38 38	0 46 40	14183.7	10 40 40
Ceres	1681 12 9 0		4 25 57 15 in 1802.		2 20 58 40 in 1802. 2 21 6 0 in 1804.		8141	9 20 8
Pallas		1703 16 48 0	10 1 7 0 in 1802.		5 22 28 57 in 1804.		24630	28 25 0
Juno	4 years 128 days.		7 29 49 33		4 21 6 0 in 1804.		25096	
Vesta	3 years 60 days 4h		2 9 42 53		3 13 1 0		9322	
Jupiter	4330 14 39 2	4332 14 27 10 .8	6 11 8 20 in 1800.	1 34 33	3 7 55 32 in 1750.	0 59 30	25013.3	5 30 38
Saturn	10746 19 16 15 .5	10759 1 51 11 .2	8 29 4 11 in 1800.	1 50 7	3 21 32 22 in 1750.	0 55 30	53640 42	6 26 42
Georgium Sidus	30637 4 0 0	30737 18 0 0	11 16 30 31 in 1800.	1 29 2	2 12 47 0 in 1788.	1 [illegible]4 35	90804	5 27 16

INSTRUCTIONS TO THE BINDER

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